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Alkali Investigations

United States Bureau of Soils

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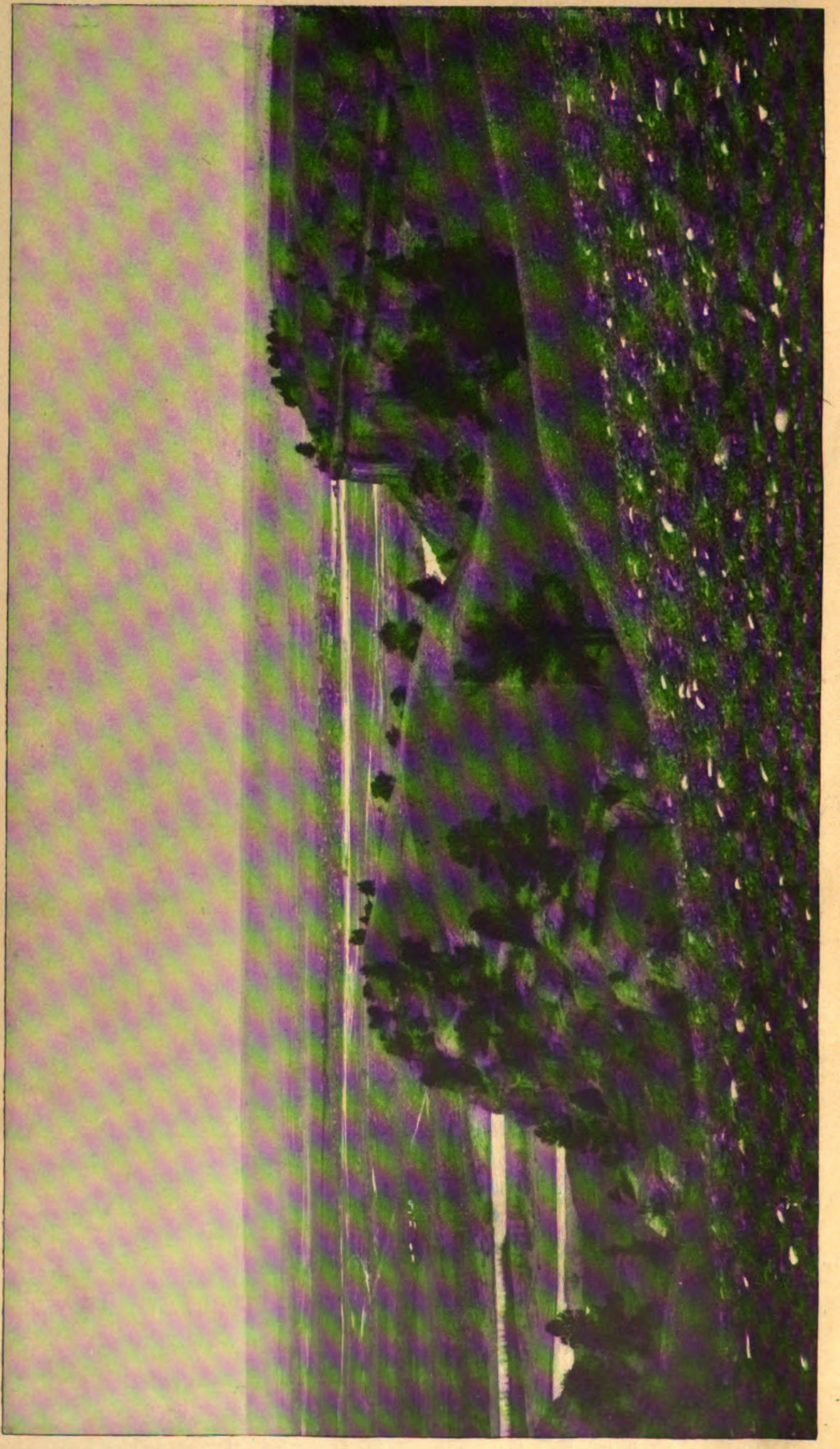

THE YELLOWSTONE VALLEY FROM THE BLUFF OVERLOOKING THE TOWN OF BILLINGS.

BULLETIN NO. 14. **S. 21.**

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

THE

ALKALI SOILS OF THE YELLOWSTONE VALLEY

FROM

A PRELIMINARY INVESTIGATION OF THE SOILS NEAR BILLINGS, MONTANA.

BY

MILTON WHITNEY and THOS. H. MEANS.

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LETTER OF TRANSMITTAL.

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U. S. Department of Agriculture,
Division of Soils,
Washington, D. C., October 22, 1898.

Sir: I have the honor to transmit herewith the manuscript for a bulletin on the results of some investigations of the alkali soils of the Yellowstone Valley. The manuscript is very fully illustrated in order that the practical side of the work can be plainly shown. Plates I–V, XVI, XVII, are from photographs taken by A. B. Rumsey, Billings, Mont. Plate XV is from a photograph by Dr. F. W. Traphagen, Bozeman, Mont.

I recommend that this be published as Bulletin No. 14 of the division.

Respectfully,

Milton Whitney,
Chief of Division.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

In August, 1897, I had a conference with the general manager and the land commissioner of the Northern Pacific Railroad at St. Paul, Minn., in regard to the character of the land through which their road runs and through which I expected to pass in a trip of reconnoissance through the Northwest. They both urged me to stop at Miles City and Billings, Mont., in the Yellowstone Valley, to investigate the alkali lands. They stated that serious trouble was threatened at these places from the rise of alkali in the soils. In opening up the country there had been no suggestion of trouble with alkali, and it was only beginning to assume alarming proportions now after some ten or twelve years of irrigation.

I stopped at Billings, and was driven over a large area of the valley at that place by several gentlemen interested in the matter. The conditions seemed so very important and there was so much uncertainty [illegible] exactly what the conditions were under the surface that I sent [illegible] to [illegible]shington for an equipment for the electrical determination of the [illegible] content of the soils, and returned to Billings when notified that this had arrived. The brief examination that was possible in the short time at my disposal satisfied me that further investigations would give results of very great practical value by showing the farmers just what the conditions were in the soil; what they had to fear if existing methods were continued; what they had to guard against to prevent the spread of alkali, and what they would have to contend with in reclaiming some of the already abandoned lands.

The following spring Mr. Thomas H. Means, an assistant in this division, was sent out to Billings to make a more detailed investigation. Owing to the small amount of money available he was only able to stay there about six weeks, but he was charged to collect data as to the general distribution of the salts with reference to the topography of the land and the position of the irrigating ditch, and to make such a detailed examination of a small area that an underground map could be constructed, showing the amount and distribution of the alkali salts under the surface. This work has been very thoroughly done, as will appear in the following pages.

The results of this investigation appear of so much practical value that arrangements are being made to continue the work and to make an underground survey of the entire valley. It is estimated that in six

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months' time and at an expense not exceeding $1,200, a sum utterly insignificant in proportion to the great value of the probable results of such an expedition, the necessary data could be collected from Billings eastward to Miles City or possibly Glendive and suitable underground maps prepared, with a view to preventing such serious calamities as have overtaken some of these lands in opening up new districts and for the reclamation of abandoned irrigated lands in the Yellowstone Valley. I sincerely trust that arrangements may be consummated for the completion of this survey.

It must not appear to those unacquainted with the subject that the rise of alkali and the disastrous effects following the application of irrigation waters is peculiar to the Yellowstone Valley. These are problems which have to be confronted in all arid regions the world over and wherever irrigation is practiced. The Yellowstone Valley was really selected to start the alkali work of the division because there the problem is so simple and the conditions can be so easily controlled. All of the irrigation districts of the country contain more or less alkali and are subject to the evil effects of overirrigation, and the community is to be congratulated where the conditions are so simple and so easily controlled as in the Yellowstone Valley.

M. W.

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THE ALKALI SOILS OF THE YELLOWSTONE VALLEY.

INTRODUCTION.

The Yellowstone Valley in Montana is approximately 400 miles in length, but the area which has been especially considered in these investigations is that part of the valley between Billings and Glendive, a distance of about 250 miles. All of the detailed work, however, mentioned in this report was done in the immediate vicinity of Billings. The valley at this point is about 6 miles in width. Irrigation has been practiced for twelve or fifteen years. The water for the main ditch supplying the valley at this point is taken out of the river nearly 40 miles above the town of Billings.

When the country was first settled and, indeed, above the ditch at the present time, the depth to standing water in the wells was from 20 to 50 feet, and there were no signs of alkali on the surface of the ground. Under the common practice of irrigation, however, an excessive amount of water has been applied to the land, and seepage waters have accumulated to such a degree that water is now secured in wells at a depth of from 3 to 10 feet in the irrigated district, while many once fertile tracts on the lower levels are already flooded, and alkali has accumulated on them to such an extent that they are mere bogs and swamps and alkali flats, and the once fertile lands are thrown out as ruined and abandoned tracts. This injury, while not very widespread as yet, has been so serious where the results have appeared that the owners of the land are naturally very much concerned. Fortunately they are prepared to receive kindly and to take advantage of all the information that can be thrown upon the condition.

Many theories have been advanced by the landowners as to the source of the alkali and as to the conditions under the surface. The belief is widespread that the alkali flats could probably be reclaimed by flooding the surface during a dry season and washing the crust off. Our preliminary investigations showed them plainly that the crust contained only a small proportion of the alkali, and convinced them that this method would not be efficient. They are beginning to realize, however, that the less water they use the safer; but still many of the planters distrust this suggestion as a possible device of the ditch management to restrict the use of water in order that it may go further and supply a larger number of customers.

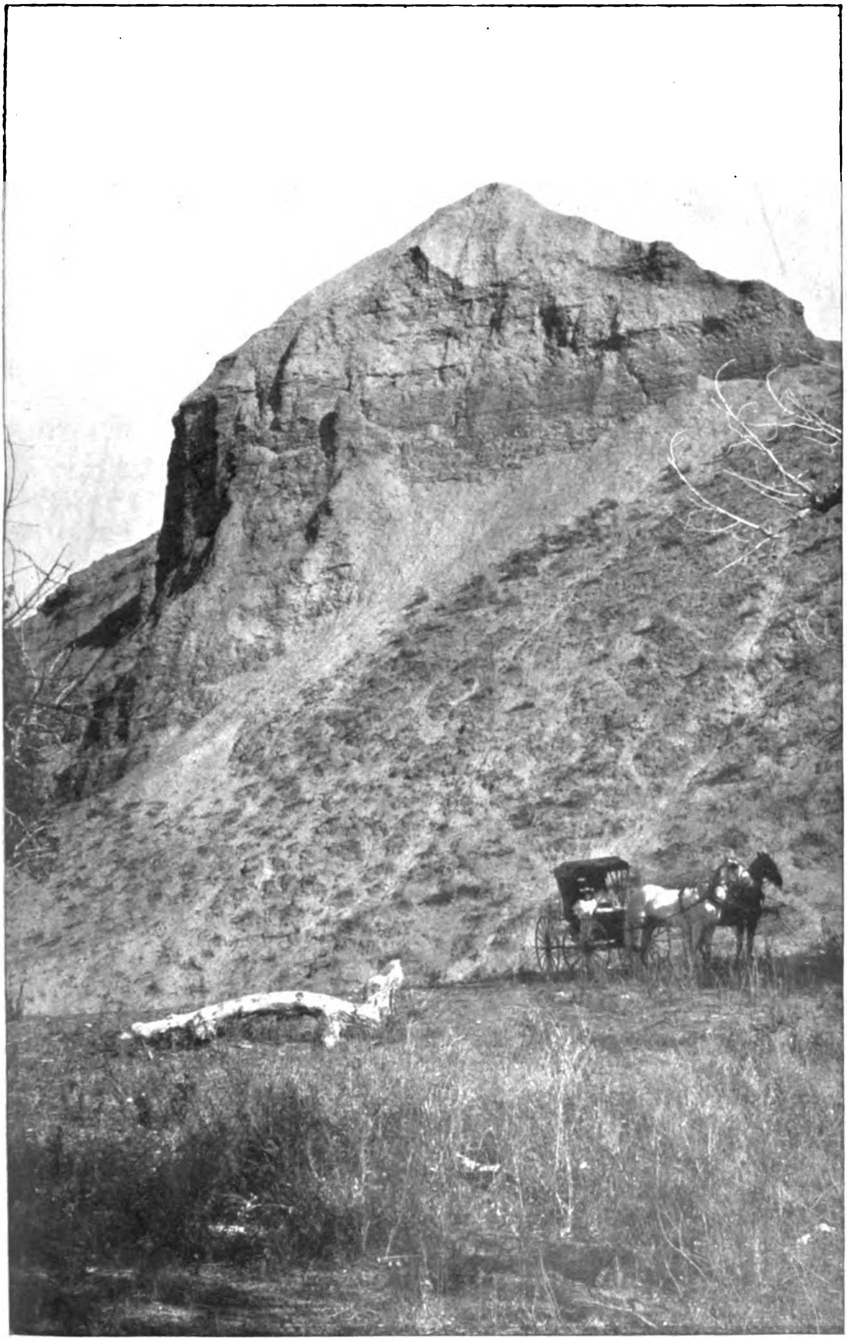
There is generally little system in the application of water to the land. Very few of the planters know how much they use, and none of them pretend to know how much they need. The water is applied when the surface appears dry, and it is then applied in such excess that much of it can not evaporate and can not seep down through the subsoil before the surface again dries out and a further heavy application of water is applied by flooding. The planters do not realize (indeed, how can they, not seeing the conditions under the surface) that the water is accumulating there, and although it may not be rising rapidly enough to injure themselves, it may be seeping down and gradually inundating their unfortunate neighbors on lower levels. In every case of injury to crops which was examined around Billings the first trouble was shown to be an accumulation of seepage water near the surface of the ground. This water is not at first excessively alkaline, but from the continual evaporation of so much water from the surface the soluble salts accumulate to an excessive and ruinous extent, prejudicial to the growth of all cultivated plants.

Hilgard has been pointing out for years that the only safe practice in bringing a new area under the ditch, in a soil which is at all likely to have alkali, is to use water very sparingly and to keep the surface under very thorough cultivation so that a minimum amount of water shall evaporate from the surface of the ground and that there shall be no accumulation of seepage waters in the subsoil.

If these investigations do no more than to show the full results of overirrigation and the necessity of intelligent and careful application of water to the soil and the importance of underdrainage, where the alkali can not be otherwise controlled or removed, the authors will be well repaid.

Proper irrigation in an arid region furnishes an ideal condition of crop production. In practice, however, the method of applying water to the land is extremely crude, and there is really little cause to wonder that much harm has been done through overirrigation, and it is no wonder that very serious trouble has occurred through the rise of soluble salts. There is less excuse for this wasteful use of water now, however. In the first place water is more valuable, and if three areas can be supplied with sufficient water from what is now applied on one area it would result not only in the advantage of an increased area brought under the ditch, but in the distinct advantage of a smaller application per acre. Furthermore, we understand now that different plants require different amounts of water for their best development, and even that the same crop requires varying amounts of water during the various periods of its development. Different soils require different amounts of water, depending upon their texture.

There is reason to hope that these principles will come to be recognized and controlled in the field as they are in the commercial greenhouses of the present time. Furthermore, the Division of Soils has invented (described heretofore) a very ingenious instrument for determining the moisture content of soils through their electrical resistance. With this instrument the amount and fluctuations of the water content near the surface of the ground or at any desired depth can be readily



A NEAR VIEW OF THE SLATE BLUFF SOUTH OF THE RIVER, WITH THE TALUS SLOPE FORMED FROM THE DISINTEGRATION AND BREAKING DOWN OF THE ROCKS.

These rocks are filled with veins of gypsum and alkali salts.

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determined, and by the use of such instrument it is quite possible, with an irrigation plant, to maintain any desired water content near the surface, and to prevent an undue accumulation in the subsoil. So important is this considered that a very simple and cheap modification of the instrument has been devised for use in irrigated fields, to cost probably not over $10 apiece, so that for a moderate expense enough of these could be distributed, even over a large plantation, so that the fluctuations of the water content of the soils of the different fields could be closely studied and controlled.

ORIGIN OF THE ALKALI SALTS.

Any excessive accumulation of soluble mineral salts in the soil is popularly spoken of as "alkali" in the West. The term, therefore, as popularly used and as used in this bulletin, does not necessarily refer to material of an alkaline or basic nature. The alkali soils of the West are of two principal classes: The alkaline carbonates, or black alkali, usually sodium carbonate, is the worst form of alkali, actually dissolving the organic materials of the soil and corroding and killing the germinating seed or roots of plants; the white alkalies, the most common of which are sodium sulphate, sodium chloride, magnesium sulphate, magnesium chloride, and occasionally, as in northern Nevada, some of the borates, are not in themselves poisonous to plants, nor do they attack the substance of the plant roots, but are injurious when, owing to their presence in excessive amounts, they prevent the plants from taking up their needed food and water supply.

Field work in the alkali soils at Billings has shown that when the concentration of the salts in active solution in the soil moisture is as high as 1 per cent the limit of most cultivated plants is reached. Further concentration kills all our ordinary agricultural plants. This is at once understood when the osmotic properties of the salts in root-cell solutions are considered. Dyer found that the acidity of root saps of a number of our common agricultural plants was equivalent in concentration to a 1 per cent solution of citric acid. The osmotic pressure in 1 per cent citric acid solution is roughly the same osmotic pressure of the 1 per cent solution of the soluble matter in the alkali soil at Billings, Mont.; so if the concentration of the soil solutions becomes greater than a 1 per cent solution the osmotic pressure of the solution outside of the cell is greater than the pressure of the solution inside the cell and the cell is unable to absorb water, the plant turns yellow, just as it would do if the soil contained too little moisture, and finally dies. This is but a rough comparison for illustration purposes only, for it is not to be supposed that the soluble matters of the root cell are all acids and acid salts. There are, unquestionably, neutral salts present which influence osmotic pressure. The real osmotic pressure in the root cells is so difficult a matter to determine that relative value only can thus be very roughly approximated for the osmotic pressure inside the cell and in the soil moisture in the alkali lands at Billings.

Hilgard states that plants will stand a larger percentage of sodium sulphate than of sodium chloride. The reason is that for the same concentration, expressed in per cents, the osmotic pressure of the sodium chloride is greater than the osmotic pressure of the sodium sulphate. Consequently a plant is able to bear more of the sulphate than of the chloride.

Some of our agricultural plants show a greater ability to stand salts in solution than others. The reason for this is probably explained by the fact that in some plants the concentration of the cell solution is greater than in other plants. The osmotic pressure of the sugar-beet root cells, for example, may be greater than those of other plants, and for that reason the beet can grow when the soil solutions are of higher osmotic pressure.

It has been found that the solid grains of soil have the remarkable power of absorbing or concentrating a portion of the salts on their surface and thus withdrawing them from active solution. This is of the greatest practical importance, as otherwise the soil moisture would quickly become saturated with salts and rendered totally unfit for agricultural plants. As a matter of fact, in consequence of this condensing power, in no case was the concentration of the soil moisture found to exceed 3 per cent, although the salts were quite soluble and were crystallized out on the surface of the ground.

The amount of soluble salts which plants can stand depends upon the character of the salt, the character of the soil, and the kind of plant. Hilgard states that few plants can bear as much as 0.1 of 1 per cent of sodium carbonate, or about 3,500 pounds per acre to a depth of 1 foot; of sodium chloride, about 0.25 per cent, and of sodium sulphate most plants can grow with 0.45 to 0.50 per cent present, and are affected by even less salts in the sandy lands than on heavy clay or gumbo lands.

The soluble salts at Billings, Mont., are mainly sodium sulphate and magnesium sulphate, with none of the sodium carbonate and with but a trace of sodium chloride. The soils also contain a considerable amount of the difficultly soluble calcium sulphate or gypsum.

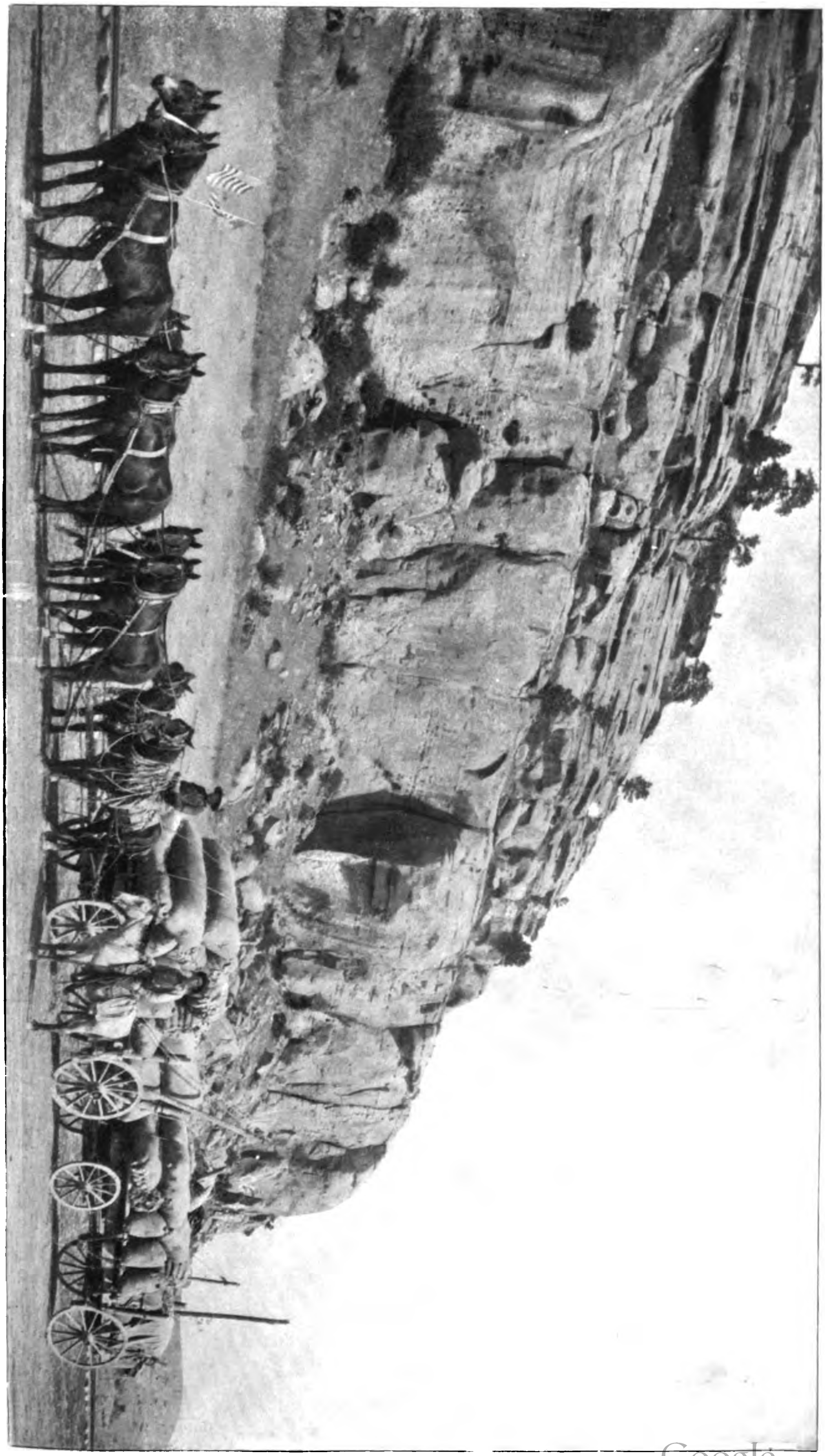
The following table gives the mean of five analyses of the soluble salts by Dr. F. W. Traphagen, of the Montana Station. From his researches the composition of the salts appears to be very constant throughout the valley.

Composition of the soluble salts at Billings, Mont.

	Per cent.
Sodium sulphate	57.44
Magnesium sulphate	27.59
Calcium sulphate	13.05
Potash sulphate	1.55
Silica	.36
	99.99

The sodium sulphate and the magnesium sulphate accumulate to such an extent in the draws and low levels that all agricultural crops

PLATE III.



A near View of the Sandstone Bluff on north side of Valley.

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are destroyed and the land abandoned. The important question at once arises as to the origin of these salts, what they have been derived from, how they were distributed in the soils before the practice of irrigation had been introduced, and how they leach and shift about in the soil as a result of overirrigation.

It is so important that a clear conception be obtained of this subject that a short space will be given to a consideration of the formation of soils and to the cause of the accumulation of such large amounts of soluble salts in the soils of the arid regions.

THE FORMATION OF SOILS.

Soils are derived from the disintegration and decomposition of rocks. It is unnecessary to speak here of the influences which occasion this decay, but it is sufficient to say that the process of the breaking down of rocks and the formation of soils is taking place with varying rapidity at every point where rocks are exposed to the action of the weathering influences.

During the weathering process the rock crumbles and breaks down into the minute particles composing the resultant soil. While the rock itself had been hard and continuous, with little appreciable space for the absorption of water and air, the resultant soil is permeated with air spaces aggregating about 50 per cent of the bulk of the soil. As one of us pointed out years ago, in the formation of the soil at least half of the bulk of the rock has been leached out and carried away, or else the material of which the rock was composed has swollen to twice the superficial volume it originally occupied. Chemical investigation has shown, however, that a very large percentage of the original rock material is actually dissolved and carried off.

The following table, compiled from the writings of G. P. Merrill, will give a general idea of the magnitude of the changes due to the solubility of the rock in the formation of soils and will give an idea of the enormous amount of material that must be decomposed and removed in order to form soil one foot in depth on an acre of land:

Amount of soluble matter removed in the decomposition of rocks and the formation of soils.

Kind of rock.	Locality.	Rock removed by solution for each acre-foot of soil formed.	
		Per cent.	Tons.
Granite	District of Columbia	13	261
Gneiss	Virginia	45	1, 431
Syenite	Arkansas	56	2, 227
Phonolite	Bohemia	10	195
Diabase	Massachusetts	15	309
Diabase	Venezuela	40	1, 166
Basalt	Bohemia	44	1, 376
Basalt	France	60	2, 625
Diorite	Virginia	38	1, 072
Soapstone	Maryland	52	1, 895
Soapstone	Virginia	78	6, 204
Argillite	Maryland	41	1, 216
Limestone	Arkansas	98	85, 760

During the weathering process, therefore, and especially in the slow decomposition of the minerals of the rock or soil, certain portions, and in the aggregate very large portions, of the rock are rendered soluble and accumulate within the soil as soluble salts, or are carried off in solution and washed off into the ocean or some inclosed basin which receives the drainage waters of the district. Through the action of water alone, or through the action of water containing minute quantities of carbonic or other organic acids, rocks of all kinds are thus slowly dissolved. In the humid portions of the United States approximately 50 per cent of the rainfall seeps down through the subsoil and runs off through the rivers into the ocean. This constant seepage through the soil prevents any excessive accumulation of soluble matters within the soil. In the arid portions of the country, however, under scanty rainfall there is not sufficient underdrainage or seepage waters to carry off the amount of salts rendered soluble in the decay of rocks, and we have, therefore, as a rule, a much larger soluble salt content in soils of the arid regions than in the soils of the humid regions. The greatest contrast is of course shown in the case of the very soluble salts of sodium, magnesium, calcium, and potassium. These are very completely removed from the soils of the humid regions. The very fact of the easy solubility of the salts renders them dangerous in the practice of agriculture when they accumulate, as in the soils of the arid West.

The kind of salt depends, of course, upon the kind of rock, and to a certain extent upon the factors producing decomposition.

The following table gives a list of the alkali-bearing minerals occurring in primary rocks as the ultimate source of the alkali of soils:

Feldspars:	Per cent of alkalies.	Micas:	Per cent of alkalies.
Orthoclase	17	Muscovite	12
Microcline	17	Biotite	10
Albite	12	Phlogopite	9
Oligoclase	9	Nepheline	24
Andesite	8	Leucite	21.5
Labradorite	4	Sodalite	26
Bytownite	3.5	Hauyn	17
Anorthite	2		

Some of these alkali-bearing minerals are very generally present in the primary rocks from which the soils have all ultimately been derived, but they are of course usually mixed with other minerals, so that the total percentage of alkalies in the rock are not so great as would appear from these minerals.

In the formation of sedimentary rocks these soluble salts are often deposited in local areas to such an extent as to form a marked feature of the subsequent geological formation of the land. Where the sedimentary rocks are formed in inclosed basins the soluble salts which have leached out of the soils in the decomposition of the rocks over the drainage area are concentrated by the evaporation of the waters of the inland lake or sea and the salts are precipitated out of solution and deposited in layers, either in a pure state or mixed with the sedimentary material that is brought down with them. Such a concentration and precipitation of salts is seen in the Great Salt Lake district of Utah, in the Dead Sea, and in the many salt lakes of central Asia. To a modified and limited extent the same accumulation goes on in the salt marshes along the coast.

The water of the ocean at the present time contains about 3½ per cent of soluble salts, having the following composition:

Composition of the dissolved salts of sea water.

	Per cent.
Sodium chloride	78
Magnesium chloride	11
Magnesium sulphate	5
Calcium sulphate (gypsum)	4
Potassium sulphate	2

Of these salts the calcium sulphate or gypsum is very slightly soluble, and on concentration of the solution this is the first salt to be deposited. The soils of the arid West are particularly rich in gypsum and carbonate of lime, and there are many extensive deposits of gypsum in beds, which are capable of being worked commercially. Such depositions from the evaporation of vast bodies of water are believed to be the origin of extensive deposits of gypsum. If the concentration continues sufficiently long the sodium chloride and the sulphates are deposited. In the salt mines at Stassfurt, Germany, the rock salt, which was formerly the substance of principal value to be mined, was overlaid with sulphates of soda, magnesia, and potash, and chlorides of potash and magnesia, while the rock salt was underlaid with very deep deposits of calcium sulphate or gypsum. There are many places in the West where the salts have deposited and where they are now depositing, mixed with large quantities of sedimentary materials and not in pure deposits of salts. In later geological ages, when these sedimentary rocks are raised to the surface and again subjected to erosion, the salts are again exposed to the solvent action of meteoric waters.

In humid regions the salts are removed by leaching almost as rapidly as the disintegration of the rocks proceeds, and there is little evidence in the soil of their former existence. However, in wells driven to the lower depths of the subsoil, where the movement of the water has been slow and the soluble salts have been only slowly and partially removed, the water is frequently charged with the soluble mineral salts. Deep-seated springs also very frequently give evidence of soluble mineral matters within the depths of the rocks, as seen in the many mineral springs in all sections of the country.

Where the rainfall is slight, as in the arid regions, and the leaching of the salt and the underlying rocks is small, the removal of the soluble matter has not gone on to such a degree. Immediately below the surface there are evidences of their presence, and in localities of very small rainfall and very scant drainage, and where the evaporation of the soil moisture has been excessive, the salts often appear as efflorescence on the surface of the ground.

The nature of the rock gives some indications of the relative amount of alkali to be found in it, as a greater amount of salts is deposited in the slow-forming shales than in the more rapid formation of the sandstone rocks. The source of the alkali salts at Billings is in the shales forming the bluffs on the south side of the valley, rather than in the sandstone of the north bluff.

The mineral elements occurring as "alkalies" in the arid regions the world over consist mainly of sodium, magnesium, and potassium, combined as carbonates, chlorides, sulphates, and occasionally as nitrates, phosphates, and borates. The alkalies themselves are derived originally from the decomposition of the feldspars and micas and three or four other minerals mentioned in the list on page 12.

The origin of the carbonic acid of the carbonates is either the atmosphere or decaying vegetation. The water percolating through the soil is charged more or less with carbon dioxide and the solubility of the rocks is very much greater in these carbonated waters than in pure water. The most important factor in rock decomposition, especially in deep-seated rocks, is the hydration—that is, the chemical combination of water with the minerals forming the rock. This action finally results in the liberation of the alkalies as carbonates and the formation of free silica and the simple silicates of alumina, magnesia, etc. The complete kaolinization of one of the feldspars indicates the processes of the formation of alkaline carbonates in the decomposition of alkali-bearing minerals.

The following equation represents the full and complete decomposition of feldspar and the formation of kaolinite and free silicic acid and potassium carbonate:

$$\begin{array}{ccccccccccc} 2K_3Al_3Si_9O_{24} & + & 6H_2O & + & 3CO_2 & = & 3H_4Al_2Si_2O_9 & + & 12SiO_2 & + & 3K_2CO_3 \\ (\textit{Orthoclase}) & & (\textit{Water}) & & (\textit{Carbonic acid}) & & (\textit{Kaolinite}) & & (\textit{Silica}) & & (\textit{Potassium carbonate}) \end{array}$$

There are, of course, many stages before the complete decomposition of the feldspar, and more complex reactions probably occur during the process, but the final products are indicated in the general changes noted by the equation, and this is the prime source of the alkaline carbonates.

The source of the sulphuric acid, which is in combination in the sodium sulphate of our alkaline plains and in combination in calcium sulphate or gypsum, is probably the oxidation of free sulphur in and around volcanic districts in the alteration of pyrite and marcasite, and in the subsequent deposition of sulphates from sea water.

Maxwell, in writing upon the Hawaiian lavas and soils, notes the occurrence of steam and water vapor containing 5 per cent of free sulphuric acid. Such acid waters coming in contact with the rocks dissolve the lime, magnesia, alumina, iron, and the alkalies with the formation of gypsum, magnesium sulphate, iron sulphates, alkali sulphates, and

A View of the Sandstone Bluff, with an Alkaline Stream in the Foreground doing its Share in Carrying off the Excess of Soluble Salts.

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several alums. The sulphates of iron thus formed readily decompose in the presence of water, forming oxides of iron, other forms of sulphate, and even free sulphuric acid. The sulphates and free sulphuric acid in contact with lime or alkali carbonates react with the formation of lime or alkali sulphates and iron carbonates or oxides, so that in the presence of pyrites or marcasite the lime or alkaline carbonates will be changed, to a certain extent at any rate, into sulphates.

There are other reactions equally important to the agriculturist besides those which have just been noted.

Hilgard has repeatedly called attention to the reactions between lime salts and the salts of the alkalies.

Where sodium or potassium carbonates or chlorides are associated with calcium sulphate in a well-aerated soil, a reaction takes place in which sodium or potassium sulphate and calcium chloride or carbonate are formed. The calcium chloride is extremely soluble and easily leached from the soil if there is any chance at all of its being carried off by drainage waters. The calcium carbonate is difficultly soluble and would remain in the soil as limestone. On the other hand, where sodium or potassium sulphate exists in the soil, together with lime carbonate and in the presence of an excess of carbonic acid or in the presence of supercarbonates of the alkalies, the reverse action takes place and carbonate of soda or potash is formed, together with the sulphate of lime.

Hilgard shows this reaction actually taking place in certain conditions of the soil. He points out that the carbonate of soda and sulphate of lime may occur in the bottom of a slight depression, where the soil is moist, while the sodium sulphate and calcium carbonate will be found around the edges where the soil is better drained. As a practical application of this matter, he urges the use of gypsum or sulphate of lime in the reclaiming of lands containing the black alkali or carbonate of soda, and at the same time points out the necessity of thorough drainage in connection with the application of gypsum; otherwise the application will do no good at all.

These various reactions and properties of the so-called alkali salts indicate the methods for the reclamation of the alkali lands. In the case of the carbonates the course recommended by Hilgard is unquestionably the proper one—to treat the soil with heavy applications of gypsum and insure thorough drainage, so as to have the soil well aerated. In the case of an excess of sodium chloride, which is very soluble and easily leached out of a soil, it is only necessary to flood the soil and remove the excess of salt in this way. It is essential, however, that the soil so treated should have good underdrainage in order that the water applied at the surface may percolate through and actually carry off the excessive amount of the soluble sodium chloride. No application of any kind will be beneficial, as the sodium chloride is as simple a salt as one can have and quite harmless, except when present in extraordinary amounts.

The treatment of soils containing sodium sulphate is more difficult than in the case of the chloride, as the salt is less easily leached from the soil. Here again no application, however, can be made, the sulphate, like the chloride, being injurious only when in large excess. It will be shown further on that the surest plan in the cultivation of these alkali soils is to use care in applying the water, so that there shall be no accumulation of the salts at the surface, and, as Hilgard has repeatedly recommended, the cultivation should be very thorough so as to prevent, so far as possible, the evaporation of the water from the surface of the ground. When the salts have once accumulated, however, there is nothing to do but wait for them to gradually leach away through the drainage and seepage waters or to thoroughly underdrain the land with tile drains, and so hasten the reclamation.

THE GEOLOGICAL STRUCTURE OF THE VALLEY AT BILLINGS.

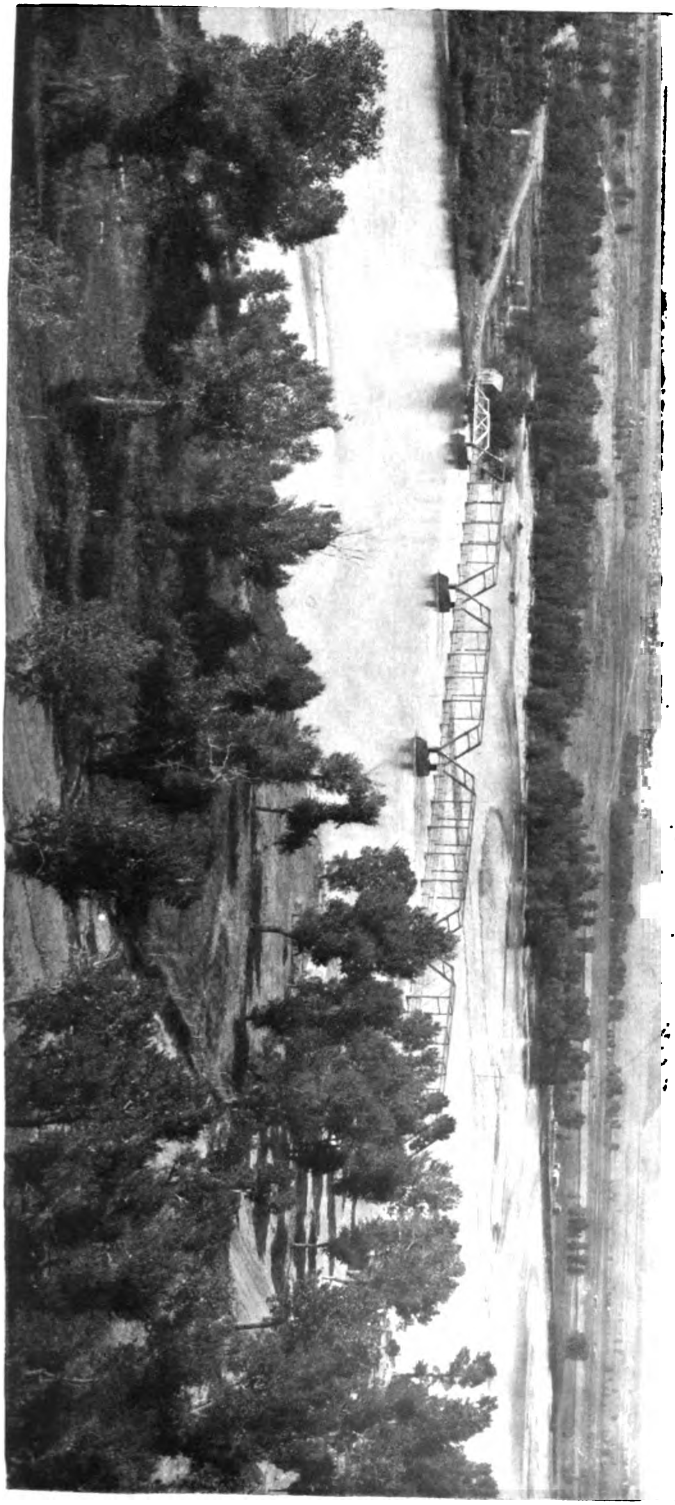
The Yellowstone River at Billings traverses a broad valley from 6 to 10 miles wide. A sketch map (fig. 1) is given of a portion of the eastern part of the valley, showing the relative positions of the irrigating ditch, the river, the site of Billings, and the bluffs on either side. The valley is bordered on either side with high bluffs. On the north side the bluff is of sandstone. On the south are steep ragged hills of blue shale. The shale or slate dips under the sandstone and is found at various depths throughout the valley.

Fig. 2 gives a diagrammatic illustration of the relative positions of these two classes of rocks. The section is drawn from north to south across the valley.

The sandstone is a gray siliceous stone, rising abruptly to a height of from 200 to 500 feet above the general level of the valley. The rocks are of the Upper Cretaceous age included in the great series of cretaceous rocks extending over the greater part of eastern Montana. The sandstone forms an excellent building stone if protected from the alkaline waters of the locality, but under the influence of these salts the stone breaks down and crumbles into loose sand. The sand grains in the rock are about 0.5 to 0.1 millimeter in diameter, and water readily penetrates the pores of the stone. Small but perceptible quantities of magnesium and sodium sulphates are to be found throughout the sandstone rocks, and where evaporation has gone on from the surface for a considerable time white crusts of these salts form on the surface.

Water seems to percolate through fine veins and cracks in the rocks and issue at the sides and the foot of the bluffs, in many places giving rise to springs of alkali water containing a greater or less amount of the soluble sulphates. Wherever this water issues, the rock disintegration has gone on to a great extent, and grottoes are formed in this way in the bluff. There are frequently hard compact layers throughout the rock, and the soluble salts accumulate just above these and are seen on the surface in the canyons and exposed bluffs as white efflorescence or layers lying parallel to the layers of hard and impervious material.

PLATE V.



General View of the Valley looking toward the Town of Billings, showing the Character of the Bottom Lands and the Drainage from the Valley.

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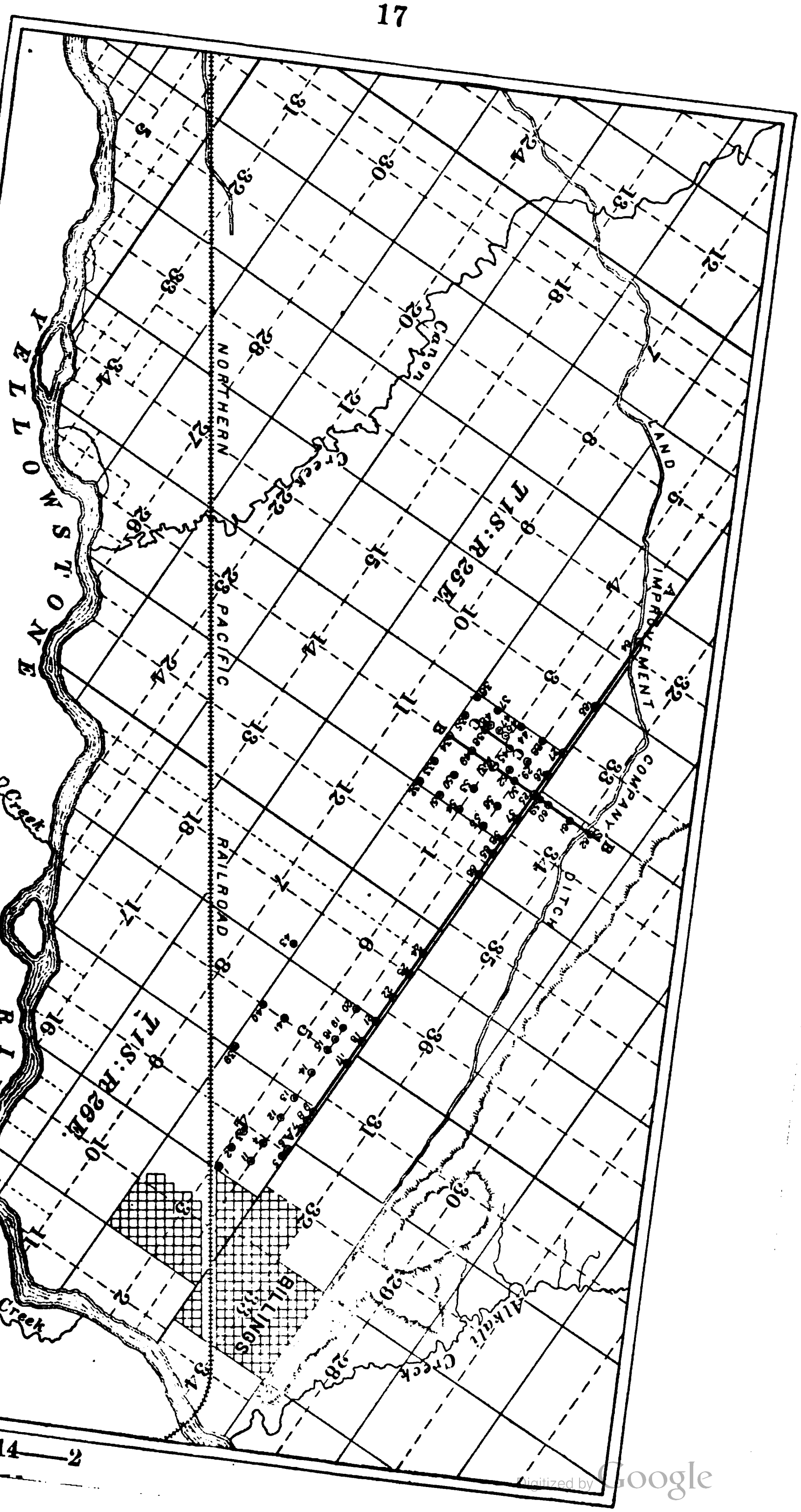
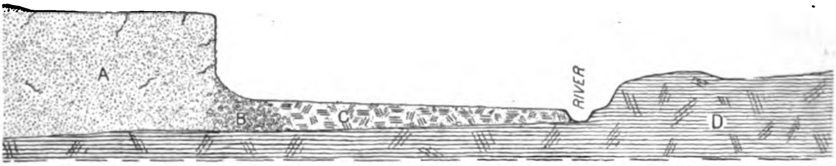


FIG. 1.—Sketch map of a portion of the Yellowstone Valley near Billings, Mont., showing the area

The main body of the sandstone has been eroded rather unevenly and the peculiar pinnacle-shaped structure is seen that is so characteristic of the Bad Lands. The face of the bluff, however, is completely rounded by weathering, and the general ragged character is smoothed off by the continual falling of the débris, due to the rapid disintegration of the rock when freely exposed to the weathering influences.

Underlying the sandstone and coming out from under the sandstone bluff there is a fine blue shale or slate which extends to an unknown depth. In an attempt to get artesian water at Billings a well was driven 900 feet through this shale. No deeper record than this has ever been made at this place. The shale rises up from beneath the sandstone and forms the rough angular blue hills on the south side of the valley.

The shale is penetrated with numerous fine cracks and joints running in all directions, and these are filled with fibrous gypsum. Many cavities also are found filled with gypsum and calcium carbonate. Everywhere throughout the shale large quantities of sodium and magnesium sulphates are found, which appear as white efflorescence where evaporation has taken place. These blue shales were deposited in the saline waters of an inland basin where lime, sodium, and magnesium salts were deposited in large quantities. If there were any alkaline carbonates or chlorides present at that time chemical reactions have taken place and the carbonates and chlorides have been changed or entirely removed from the soil, as there is little or no trace of these present except in the form of carbonate of lime. The vast quantity of carbonate of lime present indicates the possibility of the previous existence of sodium carbonate in some quantity, but if it did exist there has been a reaction between the gypsum and the sodium carbonate whereby calcium carbonate and sodium sulphate have been formed, as there is but a trace of sodium carbonate in the rocks or in the soils of the valley.



A.--SANDSTONE. B.--BROKEN FRAGMENTS OF SANDSTONE. C.--SAND & CLAY D.—SLATE.

FIG. 2.—Geologic structure of the Yellowstone Valley at Billings.

A number of illustrations (Pls. II, III, IV, and V) are given showing in general and in detail the character of the sandstone and shale bluffs which border the valley and from which the soils of the valley have been derived. The legends on the illustrations will show quite plainly the object which they are intended to represent.

The weathering of these two rocks has given rise to the soils of the valley. From what has previously been said it will be seen that the rocks themselves are the present source of the soluble salts in the valley. As the rocks weather, a portion of the soluble salts is removed in the springs and seepage waters, but the removal is not nearly so complete as is the case in the humid portion of the United States, because the small rainfall renders the escape of all of the excessive amounts of salts impossible.

The two types of rock give rise to two distinct types of soil in the valley—one a sandy soil, derived from the disintegration of the sandstone rock, giving a soil of open texture easily worked, in which there is less trouble from alkali on account of the more perfect drainage and less risk of the accumulation of seepage waters; the other type is a stiff clay or gumbo formed from the disintegration of the shales. These shale soils are extremely fertile when in good condition, but are quite difficult to work. They are easily puddled and are rendered almost impervious to water by the excess of the soluble salts which they usually contain, and it is upon these soils, with their poor underdrainage, that the greatest amount of trouble has arisen from the accumulation of seepage waters and salts in the overirrigation of the soils in the valley.

Between these two extremes of sandy soil and gumbo, in areas where the layer of sandstone has not been completely removed, the soils are blended in all possible combinations, from the pure type of the sandy soil to that of the gumbo.

The following table gives the mechanical analyses of a number of soils from Billings, which indicate the difference in the texture of the soils which has been noticed.

Mechanical analyses of soils.

No.	Locality. (Miles from Billings.)	Description.	Moisture in air-dry sample.	Organic matter.	Gravel. (2 to 1 mm.)	Coarse sand. (1 to 0.5 mm.)	Medium sand. (0.5 to 0.25 mm.)	Fine sand. (0.25 to 0.1 mm.)	Very fine sand. (0.1 to 0.05 mm.)	Silt. (0.05 to 0.01 mm.)	Fine silt. (0.01 to 0.005 mm.)	Clay. (0.005 to 0.0001 mm.)
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
3756	2½ N	Sandstone bluff soil.	1.22	2.66	0.00	0.00	0.17	29.39	52.34	3.29	0.88	9.65
3322	11 W	Silty type, creek soil.	2.98	4.40	0.00	0.00	0.16	7.96	28.79	34.45	4.67	17.25
3309	5½ W	Sandy gumbo	1.56	4.66	0.00	0.00	0.20	11.72	45.05	14.69	3.49	19.90
3308	5½ W	.....do	1.94	3.30	0.00	0.10	0.46	15.61	39.59	14.63	3.38	21.30
3307	5½ W	.....do	2.35	3.72	0.00	0.02	0.32	21.37	38.27	8.99	3.13	22.55
3306	3 W	Gumbo	3.20	3.30	0.01	0.40	1.58	20.40	27.67	11.71	4.02	27.30
3769	5 W	Heavy gumbo....	3.74	4.22	0.04	0.03	0.19	11.65	24.03	15.13	4.40	35.55

The first sample is a very pure type of sandstone soil taken from the top of the bluff about 2½ miles north of Billings and was derived from the decomposition of the soft layers of fine sandstone which cap the bluffs. These soils are very light and loose and have very free underdrainage. As a matter of fact, they leach readily, and, although they afford the best possible conditions for irrigation in that seepage waters are not likely to accumulate in them, it is probable that they would not last very long, as the soluble salts would easily and quickly be removed from them. Soils of this type are found in many parts of the valley, and there is little or no danger from seepage waters or from an accumulation of soluble salts at the surface, although they contain considerable quantities of such salts at depths below the surface.

The other samples in the table are seen to grade up through the mixed sandy gumbo to the pure form of gumbo with from 27 to 35 per cent of clay. The mixed soils are the most abundant in the valley.

METHOD OF DETERMINING THE SOLUBLE SALT CONTENT OF SOILS.

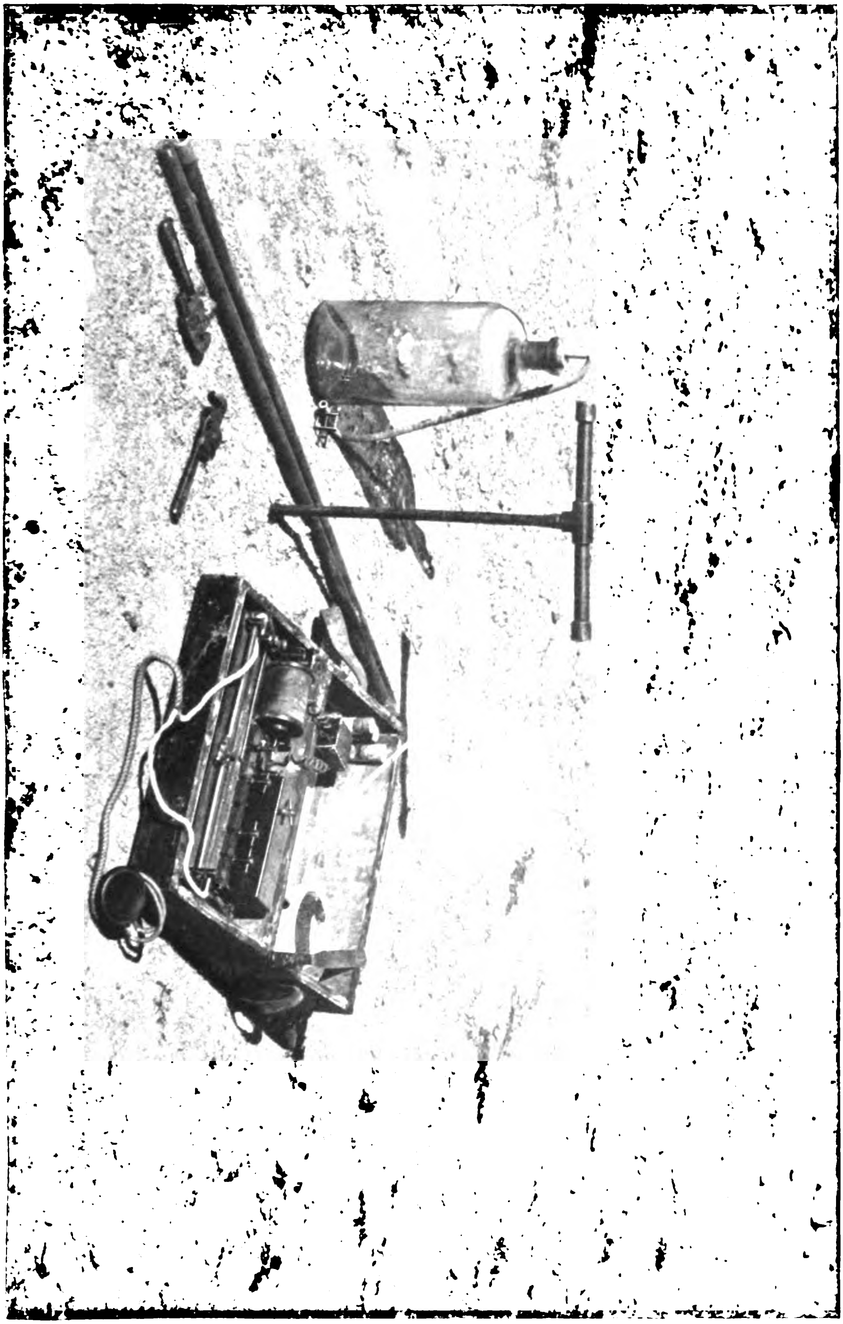
The electrical method of determining the soluble salt content of soils has been described in Bulletins 8 and 12 of this division. Briefly, the method consists in taking a sample of soil with an auger at any desired depth in the field, adding sufficient distilled water to thoroughly saturate it and bring it into the condition of a thick paste. This is then filled into a hard rubber cell with metal electrodes, and the electrical resistance of the saturated soil determined with a modification of the apparatus described in Bulletin No. 8, a full description of which will be published at a subsequent time.

The resistance so found can be taken as the resistance of a salt solution filled with inert grains of soil. The effect of the soil grains is to increase the resistance about 100 per cent. This effect is constant for all ordinary soils. The resistance of the soil moisture can be calculated by multiplying the resistance of the cell by this factor and reducing for temperature, which has previously been determined. This will give the resistance of an amount of salt solution equal to that in the cell and without the presence of the soil. The specific resistance of this solution can then be determined, and by comparing this with the specific resistance of solutions of different strength of sodium chloride or of any other salt, the actual amount of salt can be determined in terms of the salt used as a basis for comparison. In this investigation the actual composition of the alkali, as determined by Dr. Traphagen, was taken as the basis of calculation, and all of the results have been worked out in terms of this analysis, which is given on page 10.

Plate VI shows the complete outfit for the determination of the soluble-salt content of soils as actually used in the field. The sample is taken with the auger, mixed in the field in a porcelain dish with distilled water, filled into a hard-rubber cell, and the resistance is then taken. The temperature of the soil in the cell is taken. The calculations can be made there or at any subsequent time. If the amount of moisture added is once actually determined, the variations in the amount added in different experiments have very little value. The moisture determinations do not, therefore, have to be made in each case.

This method is extremely sensitive and is very rapid. The determinations can be made by one man quite as fast as the samples can be drawn by another, and much faster if the ground is hard and dry.

PLATE VI.



FIELD APPARATUS USED IN SALT DETERMINATIONS.

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Where the character of the soils vary considerably throughout the region or at different depths, it would require, of course, frequent chemical analyses to give a basis for the calculations; but over the area examined at Billings Dr. Traphagen had already shown that the alkali was very uniform in its composition, and no such frequent examinations were considered necessary.

PLAN FOR THE INVESTIGATION.

The objects of the investigations may be briefly stated. It was important to know the amount of soluble salts in the principal types of soil, which had been kept under approximately the same conditions as to exposure, cropping, and irrigation. It was important to determine the amount and distribution of the salts above the ditch where the land had never been irrigated and in the irrigated districts, and it was furthermore important to study the distribution of the salts in soils which had been or were now being ruined by the presence of alkali.

To carry out this plan three lines of borings were run—one of 5 miles in length and the others, for more detailed study, of about 1½ miles and one-fourth mile, respectively, in length. The longer section began above the ditch and went down toward the river; the others extended from an alkali flat and from a drainage ditch back into the higher levels. The position of these sections is shown on the sketch map of the valley. In each of these sections a number of borings were made and the salt content determined at every foot in depth down to 10 or, frequently, 15 feet. These borings were all numbered and their position accurately marked on the working maps. In addition to this, a section or square mile of land was studied in great detail and borings were made at frequent intervals to a depth of 10 or 15 feet. A number of special borings were also made to study the relation of the different types of soil to the amount and distribution of the salts.

The results of the investigations have been illustrated in the accompanying diagrams.

One set of the diagrams (Pls. VII, VIII, and IX) illustrates graphically the salt content of the soils found in the sections that were run; other charts (Pls. X, XI, XII, and XIII) show graphically the depth to standing water and the amount and distribution of salt for several depths in the section of land which was plotted. This gives an underground map showing the depth to standing water and the distribution of the alkali salts at several levels below the surface. Such a map is invaluable for the thorough understanding of the conditions under the soil with which the planters have to deal. If danger threatens, it shows the direction from which it is to come; where the land has already been injured, it shows exactly what the conditions are and where the cause is located. Furthermore, the method of salt determination is so sensitive and so rapid that inquiries of this kind can be readily extended over large areas with comparatively little expense.

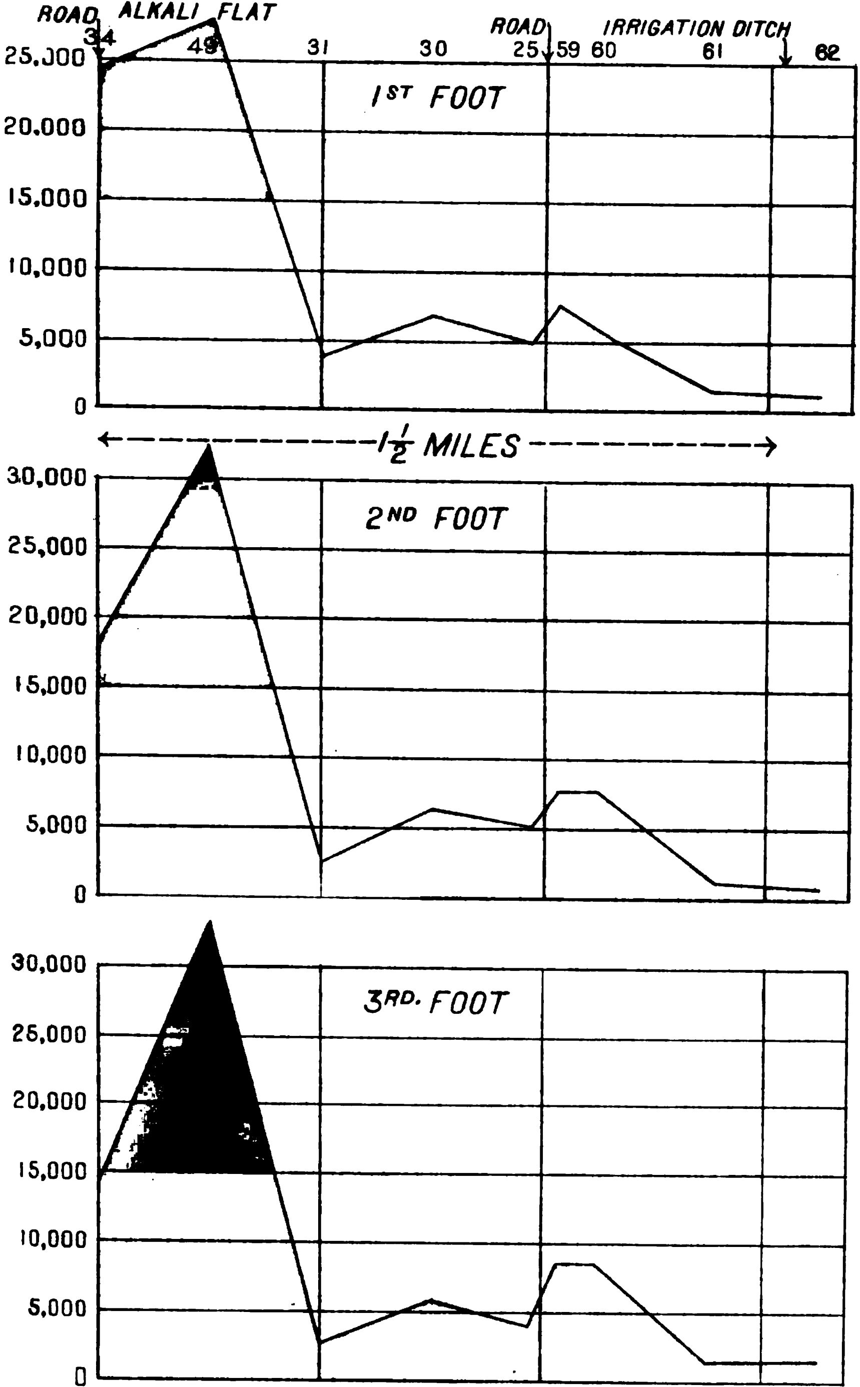
As a result of the investigations at Billings it was found that plants could just exist with 0.45 of 1 per cent of the soluble salts present, equivalent to about 15,000 pounds per acre-foot, and this is taken as the limit of plant production. The soluble salt content of soils in the humid portion of the United States ranges from 50 pounds per acre-foot in the sandy soils of the Atlantic coast to as much as 3,000 or 4,000 pounds in some of the heavier agricultural soils. The average amount would be considerably less than 1,000 pounds per acre-foot.

THE RAINFALL AND SEEPAGE.

There are no available records of the amount of rainfall at Billings, but at Miles City the Weather Bureau records show an average annual rainfall of 12.8 inches. From May to September, inclusive, there are 6.7 inches, and during July and August 1.3 inches.

Plate XIV shows a section of the soil at Billings from a cañon just below the ditch. The whole depth of the face of the exposed soil is about 20 feet. About halfway down, or at a depth of 10 feet from the surface, there appears to be a layer of water-bearing sand and gravel through which a continuous slow seepage of water takes place. This probably came from the canal, which was perhaps one-fourth of a mile away. Above this point the soil appears to be quite dry. In September, 1897, when this photograph was taken and the water was actually running, a boring was made about a mile above the ditch. The upper soil appeared to be air-dry, but about 3 feet below the surface the soil was perceptibly moist, although there had been no rain for three or four months at that time. It was stated that standing water could be found at this place at a depth of 20 or 30 feet below the surface, which would correspond with the depth of the strata from which the water was running in the cañon below the ditch. We have then the problem of a desert with standing water at a depth of from 20 to 30 feet from the surface overlaid with 20 feet of almost air-dry compact earth and with only 12 inches of annual rainfall which appears to be insufficient to soak down to this strata.

When the rains occur in the spring and wet the surface of the ranges, vegetation flourishes in the most luxuriant way and the grasses give very good grazing. The rains, however, appear to be only sufficient to wet the surface to a very slight depth, and the water is quickly used up, and true desert conditions prevail during the summer time. From all the evidence it does not seem probable that the rainfall reaches down into the water-bearing strata to any great extent. It is not probable that the water-bearing strata is supplied from the local rainfall. It appears that in the dry season the soil is moist from 3 feet down, but so slightly moist and the depth of the dry material is so thick that it is altogether unlikely that the spring rains pass down to any appreciable extent locally in any one year. The conditions, therefore, are unfavorable to a natural leaching of these soluble salts except through the exceedingly slow movement there may be in the slightly moist subsoil.



SECTION B. THROUGH BORINGS 34 TO 62.

SALT CONTENT FROM A LINE OF BORINGS ONE AND A HALF MILES OUT FROM AN ALKALI FLAT. THE BLUE COLOR INDICATES THE EXCESS OF SOLUBLE SALTS.

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SALT CONTENT OF THE SOIL.

An investigation was made of the salt content of a marked type of the sandy soil from above the ditch upon which water had never been applied through methods of irrigation.

The following table shows the amount and distribution of the salts in two places:

Amount of soluble salt in sandy soil.

UNIRRIGATED.

Depth (feet).	Boring 62.		Boring 64.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0- 1	0.033	1,155	0.042	1,470
1- 2	.019	665	.041	1,435
2- 3	.045	1,575	.035	1,225
3- 4	.027	945	.038	1,330
4- 5	.032	1,120	.045	1,575
5- 6	.028	980	.055	1,925
6- 7	.019	665	.056	1,960
7- 8	....	....	.170	5,950
8- 9	....	....	.238	8,330
9-10	....	....	.243	8.505
10-11	....	....	.205	7,175
11-12	....	....	.120	4,200
12-13	....	....	.163	5,705
13-14	....	....	.228	7,980
14-15	....	....	.178	6,230

It will be seen that there is not sufficient soluble matter down to a depth of 15 feet to prevent the growth of agricultural plants, as the amount does not approach the limit of 0.45 per cent, or 15,000 pounds per acre-foot. It is interesting to note, however, that the amount of soluble salt in the upper 7 feet of the soil is particularly small. There is 50 per cent more, perhaps, than is ordinarily found in the soils of the humid region. Below a depth of 7 feet, however, the amount of salt is considerably increased. It would appear that there were evidences here of a slow downward movement of soil moisture, and that under these constant conditions of slow seepage the amount of salt in the upper layers of the soil was constantly diminishing. No examinations could readily be made of the soil below a depth of 15 feet, as this was the extreme length of the auger, but from information furnished by some well-diggers thoroughly familiar with the locality it was learned that the soluble salt content increases below this to very large proportions. White layers strongly impregnated with salts are said to be found below this depth. The water from the wells contains too much of the salts to be of use for domestic purposes, although it is not so strong as to be harmful to cattle.

It is quite reasonable to suppose that the soluble salts had originally been uniformly distributed throughout the upper layers of these soils, and that from storm waters and the slow seepage of the slight amount of moisture which the subsoil contains the soluble material has been washed down from the upper layers. Certain it is that similar results follow from the first effect of irrigation where there is good underdrainage, as generally prevails in this sandy soil.

Borings were made in the same character of soil below the ditch and only a short distance away. The following table gives the salt determinations in three borings made in this irrigated sandy soil:

Salt determinations in irrigated sandy soil.

Depth (feet).	Boring 26.		Boring 27.		Boring 28.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0- 1	0.046	1,610	0.038	1,330	0.033	1,155
1- 2	.049	1,715	.045	1,575	.037	1,295
2- 3	.052	1,820	.044	1,540	.028	980
3- 4	.066	2,310	.051	1,785	.030	1,050
4- 5	.097	3,395	.060	2,100	.048	1,680
5- 6	.106	3,710	.051	1,785	.048	1,680
6- 7	.128	4,480	.064	2,240	.048	1,680
7- 8	.147	5,145	.070	2,450	.047	1,645
8- 9	.112	3,920	.049	1,715	.047	1,645
9-10	.112	3,920	.049	1,715	.047	1,645
10-11	.056	1,960	.072	2,520	.044	1,540
11-12	.056	1,960	.072	2,520	.044	1,540
12-13	.058	2,030	.072	2,520	.044	1,540
13-14	.058	2,030	.072	2,520	.044	1,540
14-15	.058	2,030	.072	2,520	....	....

It will be seen in this case that the amount of soluble matter, even to a depth of 15 feet, is comparatively small, and the amount throughout the whole depth is quite uniform. This indicates very strongly that the salts have been leached out of the soil and carried off in the underground drainage waters. The examination of the water in a well situated in this irrigated area of the sandy land gives additional proof that some of the salts have been removed. There is a well at the southwest corner of section 2, near boring 44, in which the water contains 0.119 per cent of soluble matter, or 60 grains per gallon. Other wells throughout the irrigated area frequently contain as much as 0.4 per cent of salts.

Where this sandy soil is overirrigated, or where from some physical cause the subsoil is compact and the drainage is poor and water accumulates within the subsoil, the seepage waters which move rapidly accumulate and frequently come up to the level of the surface of the ground. Under these conditions excessive evaporation sets in from the surface and salts accumulate until the soil moisture is so saturated that the salts are deposited at the surface as a crust. Such alkali flats are frequently found on the low levels of the Billings area, even in these sandy soils.

The following results indicate conditions in one of these alkali flats, where the sand is underlaid at a slight depth with a heavy gumbo subsoil:

Salt determinations in an alkali flat in the sandy soil.

Depth (feet).	Boring 49.		Boring 52.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0-1	0.792	27,720	0.229	8,015
1-2	.920	32,200	.191	6,685
2-3	.944	33.040	.182	6,370
3-4	.792	27.720	.175	6,125
4-5	.519	18,165	.159	5,565
5-6	.519	18.165	.213	7,455
6-7	.357	12,495	....	....
7-8	.357	12,495	....	....
8-9	.292	10,220	....	....

It will be seen that in boring 49, which was in the midst of the alkali flat, there was an excessive accumulation of alkali, beyond the limit of any agricultural plant, at least to a depth of 7 or 8 feet. Below this it rather looks as though the amount of salts was diminishing and that if the boring could have been carried deeper the salt content would perhaps have grown less.

In both these borings standing water was found between 1 and 2 feet of the surface of the ground. Evaporation had been going on for a number of years, the seepage waters being supplied by the overirrigation of lands on higher levels. At the present time the soil in boring 52 does not contain an excessive amount of alkali for the alfalfa, but the level of standing water is so near the surface that the roots of the plants are submerged and the crop can not be successfully grown. This is the first stage in the ruin and devastation that is being wrought, and boring 49 shows the final and complete stage when the land is given up to water and alkali.

When land is in the condition of boring 52, and before any notable accumulation of crust has appeared upon the surface, the land becomes covered with a heavy growth of weeds. All agricultural crops have ceased to grow for some time, and the land has been left out as a barren waste. Such a condition as is shown by the growth of weeds is usually thought to mean that the alkali is disappearing or is being used up by the weeds themselves and that the soil is again becoming fit for crops. In some cases this may be true, if there is sufficient drainage to carry off the excess of seepage waters; but in many cases the conditions simply indicate that the weeds are a class of plants which can thrive on wet ground and grow for a while luxuriantly. If the methods of irrigation are kept up and the seepage waters continue to collect and evaporate for a few years longer, alkali accumulates in sufficient quantities to kill even the growth of weeds, and the land truly presents the appearance of a desert.

Some of the planters are much inclined to accept the prevailing conditions and to look for crops like the Australian salt grass, which will grow in these alkali flats and wet soils. It is wrong to accept these conditions, however, and depend upon these makeshifts, when the conditions ought in the first place to have been prevented and ought now to be removed by radical and energetic methods of drainage or through better and more careful methods of irrigation.

From all the facts thus far observed it can be said that the first harmful effect observed in these sandy soils is caused by an excess of water, and if this is not immediately lessened further damage will result from the accumulation of soluble salts. If the excess of water is soon removed no permanent damage will result.

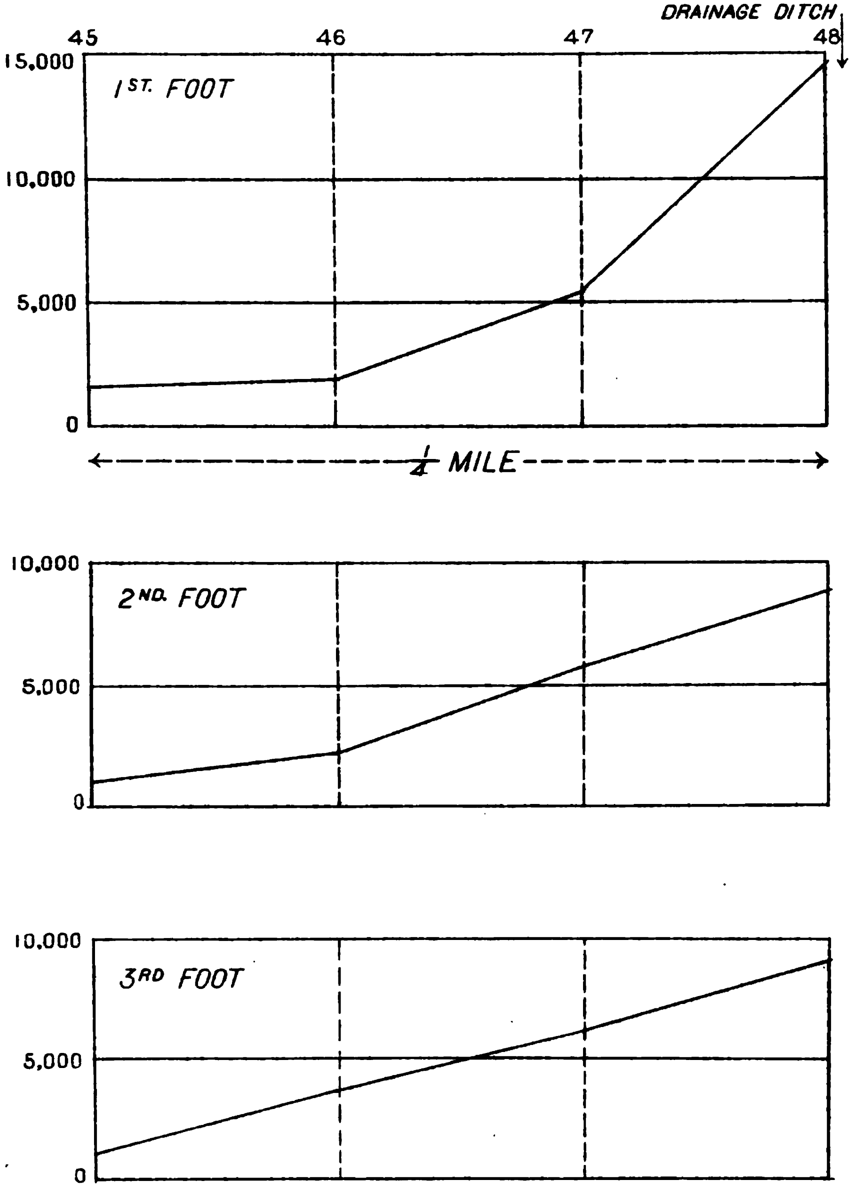
The heavier type of soil—that is, the gumbo soil—was shown to be derived from the disintegration of the shale. The still undecomposed shale in the bluffs on the south side of the valley was found to be penetrated in every direction with veins of gypsum and the soft shale itself to be permeated with large quantities of sodium and magnesium sulphates. The soils resulting from the disintegration of the shale form a heavy, sticky, blue clay quite impervious to water. The drainage is so slow through this fine, impervious material that large quantities of the salts remain in the soil.

On account of the poor drainage and the slow movement of the subsoil waters through this material there is great danger of overirrigation, and the problem of irrigation, which is easy on the well-drained, sandy lands, becomes far more complicated and much more difficult to manage on these heavy gumbo soils. Great care has to be taken, not only in the application of water, but in the actual cultivation of these soils, as they are liable to be ruined for a time at least for alfalfa. On account of the large water content, the fineness of the particles, and the amount of salts these soils contain they easily puddle, and if they are worked when too wet clods form and it is very difficult to reduce the field again to a good tilth.

On account of these properties the heavier or gumbo soils have to be farmed with very great care. Not only so, but there is great danger from seepage waters from neighboring plantations on higher levels. The soils themselves are naturally extremely fertile and very strong and last very well if well cared for. The following table gives the results of salt determinations in typical gumbo soil above the ditch, which has never been irrigated.

The salt content of a heavy unirrigated gumbo soil.

Depth (feet).	Per cent of salt.	Pounds per acre-foot.
0–1	0.035	1,225
1–2	.038	1,330
2–3	.054	1,890
3–4	.200	7,000
4–5	.333	11,655
5–6	.337	11,795
6–7	.253	8,855
7–8	.253	8,855
8–9	.282	9,870



SECTION C THROUGH BORINGS 45 TO 48.

SALT CONTENT FROM A LINE OF BORINGS EXTENDING ONE-QUARTER MILE BACK FROM A SMALL DRAIN IN AN ALKALI FLAT.

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It is apparent from the table that there is a considerable quantity of salt at a depth of 5 feet and from there down. This boring, with others, is illustrated graphically in fig. 3.

When water is applied to this gumbo soil in the practice of irrigation, the first effect is to reduce the amount of soluble salts in the upper layers of the soil. If there is good drainage this excess of salt may be removed altogether from the soil. If the drainage is slow and inefficient, however, or in case of a large excess of seepage waters from higher levels, the water soon accumulates in the subsoil and quickly rises and drowns out all vegetation. If the conditions remain in this way for some time and evaporation is allowed to continue, enormous

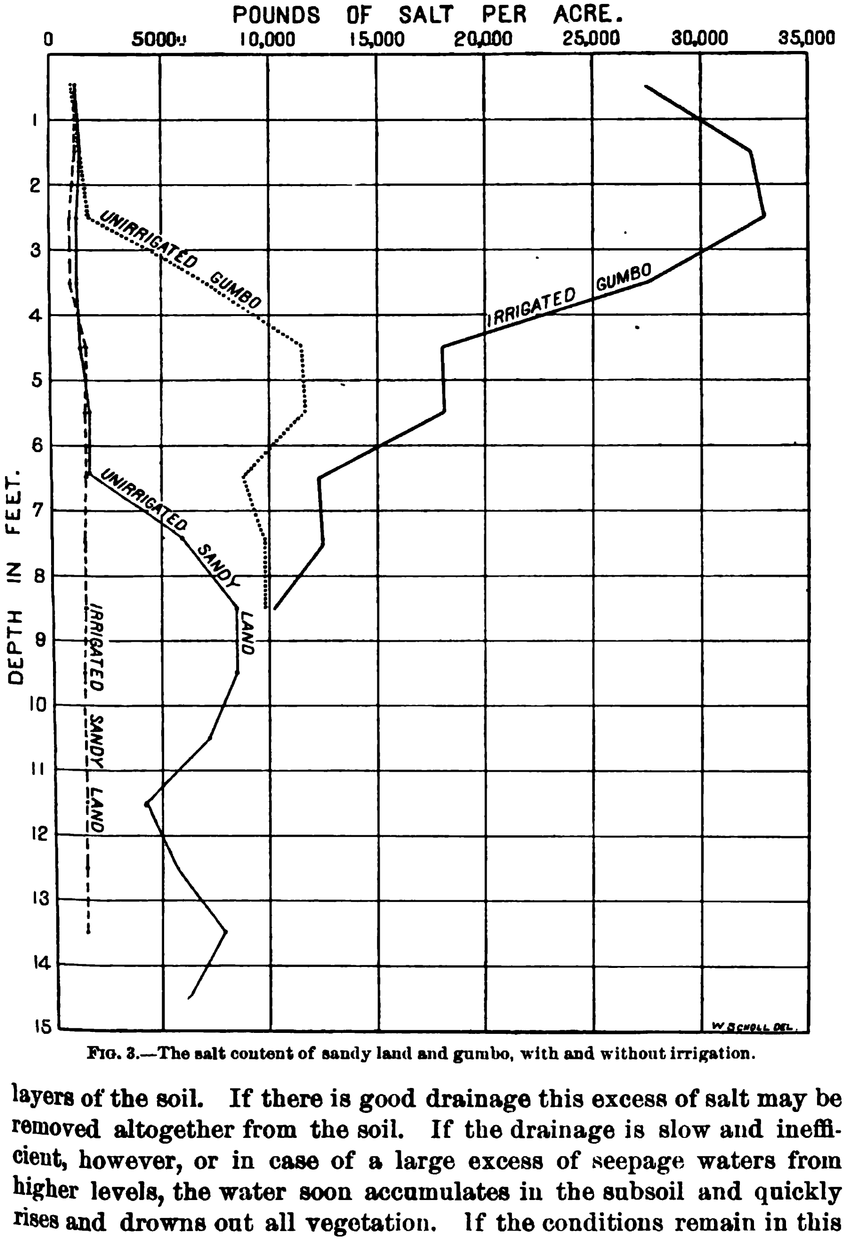


FIG. 3.—The salt content of sandy land and gumbo, with and without irrigation.

quantities of salt accumulate in the upper layers of the soil, and the land is finally turned out as an alkali flat.

The accompanying table shows the salt content of an alkali flat in this gumbo soil to a depth of 6 feet.

Amount of soluble salts at different depths in overirrigated gumbo land.

Depth.	Boring 36.	
	Per cent of salt.	Pounds per acre-foot.
0-1 inch..	1.023	a2,975
0-1 foot..	.757	24,710
1-2 feet..	.714	34,570
2-3 feet..	.634	21,105
3-4 feet..	.612	21,035
4-5 feet..	.589	20,965
5-6 feet..	.187	6,650

a Pounds in acre-inch equivalent to 35,700 pounds in acre-foot.

It will be seen that the salt has accumulated to enormous proportions in the top 5 feet of the soil. The conditions show that the solution is so strong that a white crust is formed over the surface. However, on account of the absorptive powers of the soil, the solution immediately under this crust and in contact with the soil was only 3 per cent, notwithstanding the fact that the salt ordinarily is very soluble in water. A solution of this strength, however, is entirely too strong for any cultivated crop, and the alkali flat presented a very desolate appearance, as seen in Plate XV.

A line of borings was run from the center of this alkali flat for a mile and a half back to the main canal. A number of borings were made to a considerable depth and salt determinations calculated for every foot in depth in each of these borings. The result of these investigations for the top 3 feet is shown graphically in Plate VIII. In this illustration the span bounded by the curve above the line of 15,000 pounds per acre represents the relative area in which there is an excess of alkali and the amount of this excess. It will be seen that adjoining the canal and for two-thirds of the way down to the alkali flat there is but little alkali, as though the irrigation water had removed the salts from this portion of the land and that they had then accumulated in the alkali flat, which is at a somewhat lower level. These irrigation waters slowly seep through the underground channels down into the natural drainage system, which is represented in this case by the alkali flat on account of its somewhat depressed condition. The salts first appear in these low places in the line of underdrainage and as the evaporation of the water goes on the salts accumulate, gradually extending up and enlarging the alkali flats as the water rises until the level of the surrounding area is reached, when the whole district is abandoned. Along the line represented in this diagram the area around and back from the alkali flat is first-class alfalfa land and the property is considered very valuable, but only three or four years ago the alkali flat itself was considered just as valuable, and the alarming feature of the whole thing is that the owners know that, if these conditions continue, the alfalfa field itself will be ruined and will have to be abandoned in a few years unless very energetic means are taken to arrest the progress of the trouble.

The chances are, of course, that this condition has not arisen from the local application of water at this place. It is possibly a result of injudicious methods of irrigation on the adjoining lands at higher levels. One of the most discouraging features of the whole problem is that the owner of such a tract of land may use the most approved methods of irrigation, and yet be completely ruined by the excessive and injudicious use of water by his neighbor, who may himself escape the injurious effects of his own crude methods, at least for many years after his neighbor has been ruined. In the contemplation of such a problem as is presented in the Yellowstone Valley, therefore, there are certain property rights that may easily be abused, causing very disastrous results to appear upon a neighbor's property. It makes the whole problem very difficult to deal with, especially as it would be extremely difficult to show the source of the trouble and to locate the offending person. It is a problem, however, which will have to be taken up; and if the property owners do not themselves take adequate care of their drainage systems and use intelligent methods of irrigation, some means must be found of compelling them to do so, or to give redress to their unfortunate neighbors.

This accumulation of salts is very harmful in the puddling effect on the soil. The flocculation of the soil grains is broken up and the grains are separated out into their most uniform position, where they offer the greatest possible resistance to the flow of water. This puddling can only be relieved by draining off the water and salts, and this drainage is rendered exceedingly difficult by their presence, so that the reclamation of these alkali flats on the gumbo soil is an exceedingly difficult, slow, and expensive undertaking.

The formation of these alkali flats is in a way an evidence of the effort of nature to correct the faults of our crude system of irrigation. The salts are being carried off into the natural drainage of the country, but the process is very slow and the excess of seepage water and the salts themselves collect in these places on account of the inability of the soil to let them pass as rapidly as the excess of water is supplied. This suggests the only feasible method of reclaiming these lands and, indeed, of preventing the accumulation of the salts which will occur except under the most careful and judicious methods of applying water. In cases like that under consideration, where the damage has already been done, the natural drainage is so slow that it does not afford adequate relief, and in fact is but a sign of impending ruin for a very much larger area. The only way to reclaim the land is to put in an efficient system of drains, preferably of underground tile drains. It is urged against this idea that the land is not worth the cost of the investment in putting in a system of tile drains. This, of course, is an economic problem which is entirely dependent upon conditions of market, transportation facilities, and other commercial considerations. It may or may not be profitable at this time to protect the lands from destruction and to reclaim those that have been destroyed. It may be cheaper to move off into new areas, but the time will come, if it has not already come, when the land in the Yellowstone Valley and in similar situations will be worth the care and expense necessary to protect it from ultimate destruction. The amount of money now invested in the Yellowstone Valley is enormous, and the continuance of prosperity is entirely dependent upon the care which is taken in the methods of irrigating the lands. Property worth thousands of dollars may be ruined in a few years and become utterly worthless. The experience in the valley shows that this has been the case in the past, and there is much uneasiness felt in regard to large areas which show signs of the rapid spread of alkali. (See Pl. XV.)

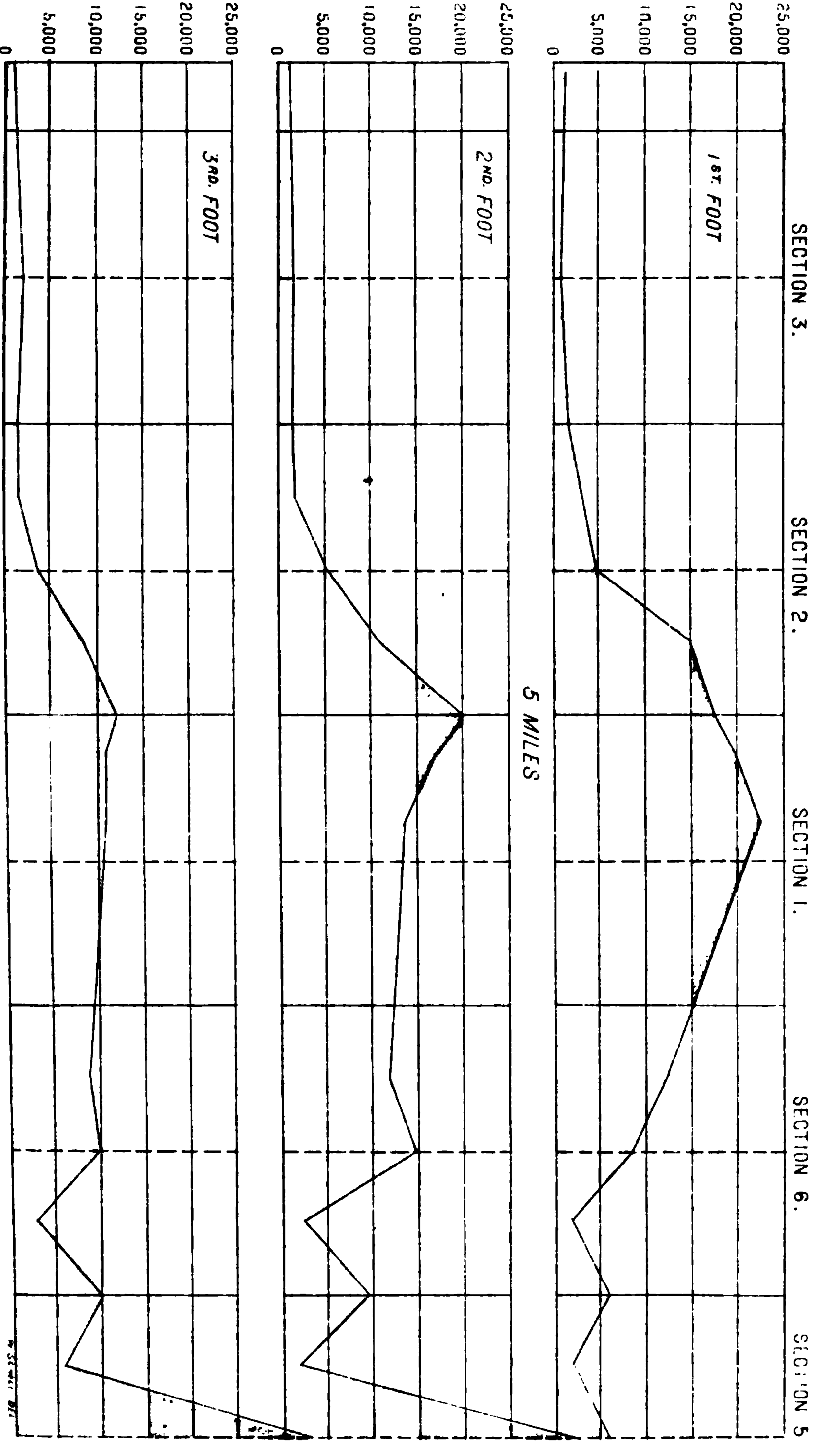
There is abundant evidence that thorough underdrainage will reclaim these lands, and if introduced in time will prevent any such disastrous results as those which have been described. There has been no thorough system of tile drainage tried, but a few efforts have been made to reclaim the abandoned lands by open drains. That these have been efficacious the following investigations will show:

A drainage ditch had been dug in the alkali flat on section 2 and the excess of water had been continuously removed for some time before this investigation was made. A line of borings was made from this ditch back about one-fourth mile to see how the salt content had been changed. The results of the determinations for the top 3 feet is shown graphically on Plate VIII, and the actual determinations are given in the accompanying table, which represents the per cent of soluble salt found at different distances from this ditch.

Salt determinations at different distances from a drainage ditch.

Depth (feet).	Boring 45.	Boring 46.	Boring 47.	Boring 48.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0–1	0.047	0.054	0.155	0.419
1–2	.030	.066	.164	.253
2–3	.036	.112	.177	.257
3–4	.031	.103	.213	.238
4–5	.045	.109	.191	.275
5–6	.045	.120	.191	.267
6–7	.043	.138	.225	.275
7–8	.043	.162	.237	.337
Average	.040	.108	.194	.290
Total pounds per acre 8 feet deep	11,200	30,280	54,320	81,200

Boring 46 shows the amount of salt about 300 yards from the drainage ditch. The next column shows the amount at about 100 yards from the ditch, while the last column shows the amount closely adjoining the ditch. It will be seen from this table and from graphic representations



SECTION A. ALONG RANGE LINE

SALT CONTENT FROM A LINE OF BORINGS 5 MILES LONG ALONG THE RANGE LINE. THE BLUE COLOR REPRESENTS THE EXCESS OF SALT.

(Plate VIII) how the salts have accumulated at the lowest point of the drainage system and how they are being removed by the drain as the water from the irrigating ditch seeps down and the excess of seepage water is carried off. The amount of salt found at the drainage ditch is already below the 15,000 pounds limit of crop production, while farther out in the alkali flat, under presumably the same conditions as existed at the drainage ditch when it was cut, the amount of salt is upward of 35,000 pounds per acre-foot.

It is easy to show in another way the beneficial effects of underdrainage. The land around Billings is underlaid at a depth of from 6 to 8 feet by a layer of gravel. Within the last few years it has been necessary to construct a ditch around the town of Billings to cut off from the town the seepage waters from the irrigated lands. This ditch is cut to a depth of 6 or 8 feet, so that it is in the gravel through its whole length, and it receives the water from two or three natural draws and all of the seepage water from four or five sections of land. No sewage is allowed to flow into the ditch from the town.

A number of observations were made upon this ditch during the month of June. It was estimated that the average flow of water during this time was about 40 cubic feet per second. Frequent determinations were also made of the soluble salt content of the water flowing in this drainage ditch.

The following table gives the amount of salt found during the month of June:

Examination of drainage water.

	Salt (per cent).	Tons of salt removed per hour.
June 4	0.302	13.6
June 6	.424	19.1
June 7	.422	19.0
June 11	.449	20.2
June 12	.283	12.7
June 13	.481	21.6
June 16	.227	10.2
Average	.370	16.6

It will be seen that the ditch is doing a great work in removing the salt content from the overirrigated lands around the town. At the rate at which the salt was being removed at the time these observations were made, the ditch was removing about 16½ tons per hour. If this rate was continuous, it would drain 1 per cent of salt from the upper 5 feet of about 900 acres of land per year. As a matter of fact, while the ditch rarely if ever stops flowing, the flow is not always as great as during the time of this investigation. Still the figures give some idea of the enormous results which may be accomplished by a judicious system of drainage in the reclamation of these alkali lands and the protection from an undue accumulation of salt and seepage waters.

Plate I (frontispiece) gives a distant view of the town of Billings from the slate ridge over toward the sandstone ridge on the other side of the valley. This portion of the valley has been almost swamped with seepage waters and ruined with the rise of salts. The white crust of alkali shows in the illustration as covering most of this portion of the valley for 3 or 4 miles from the town of Billings. It is through this area that the drain just mentioned has been started. It may be well to state that the water in the main irrigating canal (Pl. XVI) that is taken out of the Yellowstone River about 40 miles above Billings is very free from alkali, the water, therefore, being used for irrigating purposes, although carried for this great distance through the valley, was fresh and free from salts. From all sources, however, where this water was escaping as seepage water it is seen to be loaded with excess of salts, and where free to flow off readily the salts will be carried off instead of accumulating in the alkali flats.

Besides the examination of the drainage ditch around the town of Billings many determinations were made of the salt content of springs and wells. The following table gives the determinations of the salt content from a number of places.

Salt content of springs and wells near Billings.

	Per cent.
Spring on the sandstone bluff	.029
Well on west side of section 2	.119
Spring on west side of section 2	.212
Well on north side of section 2	.309
Spring on north side of section 6	.433
Spring in center of section 5	.437
Well on south side of section 1	.536
Well on north side of section 2	.538

Well water containing more than one-tenth of 1 per cent is ordinarily considered unfit for domestic use. In most of these wells the water was less than 5 feet below the surface of the ground, and the water tasted strongly saline.

It will be seen, therefore, from all of these sources that the water in the soil is charged with this excess of salt. If there is a ready means provided for it to leave the soil, there will be no excess of soluble salts. It would, of course, be unfortunate to depend upon this to carry off the salts from reckless overirrigation, for in removing these salts much valuable plant food may also be lost and the soil in a measure impoverished. It is necessary, therefore, even with a system of efficient underdrainage, to use great care, so that there shall not be more loss through underdrainage than is necessary. It is perfectly evident, however, on the other hand that if these conditions continue and the water rises closer to the surface than it is at present, that the seepage waters and the accumulation of salts together are likely to prove very disastrous over larger areas.

UNDERGROUND MAPPING OF THESE SOIL AREAS.

Having found the source of the alkali salts in the sandstone and slate rocks which border the valley from which the soils of the valley have been derived, and having determined the character of the soils resulting from each class of rocks, the texture and relation of these to the alkali salts, to underdrainage, and to seepage, the next step was to make a detailed examination of such an area as time would permit for the construction of an underground map, which should show the amount and distribution of the soluble salts at different levels below the surface. For this purpose a preliminary line of borings was made for a distance of about 5 miles along the range line, as indicated on the sketch map of the valley. Borings were made at frequent intervals and the amount of salt determined for every foot in depth. Plate IX shows graphically the amount of salt found in the top 3 feet of the soil along the range line. The line goes just beyond section 3 in the sandy prairie above the ditch, and continues throughout section 3 in the same character of soil, in which the amount of alkali is quite small and no larger than is ordinarily found in the soils of the humid regions. Beyond this the heavy gumbo soils prevail, and the seepage waters have accumulated and the salts have accumulated until the whole of section 1 and a part of section 2 are lying out as an alkali flat. This accumulation of salt and the accompanying accumulation of seepage waters which cover section 1 along this range line, is gradually extending and covering larger and larger areas.

A detailed examination was finally made of section 2, over which the ruin caused by the rise of seepage waters and the accumulation of salts was well advanced. The level of standing water was determined as well as the amount of salt to a depth of 10 or 15 feet. From this examination maps have been constructed, several of which are given in this bulletin, illustrating graphically the amount and distribution of salt in the top 3 feet of soil. The depth to standing water is illustrated on Plate X, with contour lines showing the depth in feet from the surface of the ground to the level of standing water at the time of the observations. The other plates represent with contour lines and with different tints different amounts of alkali salts. The green color on Plate X shows the area over which the depth to standing water is less than 2 feet from the surface and over which, for this reason, alfalfa will no longer grow. On the other plates, XI, XII, and XIII, the blue color represents the area containing over .45 per cent, or 15,000 pounds per acre-foot of soluble salts, which is taken as the limit of profitable crop culture. These plates are fully described in another place.

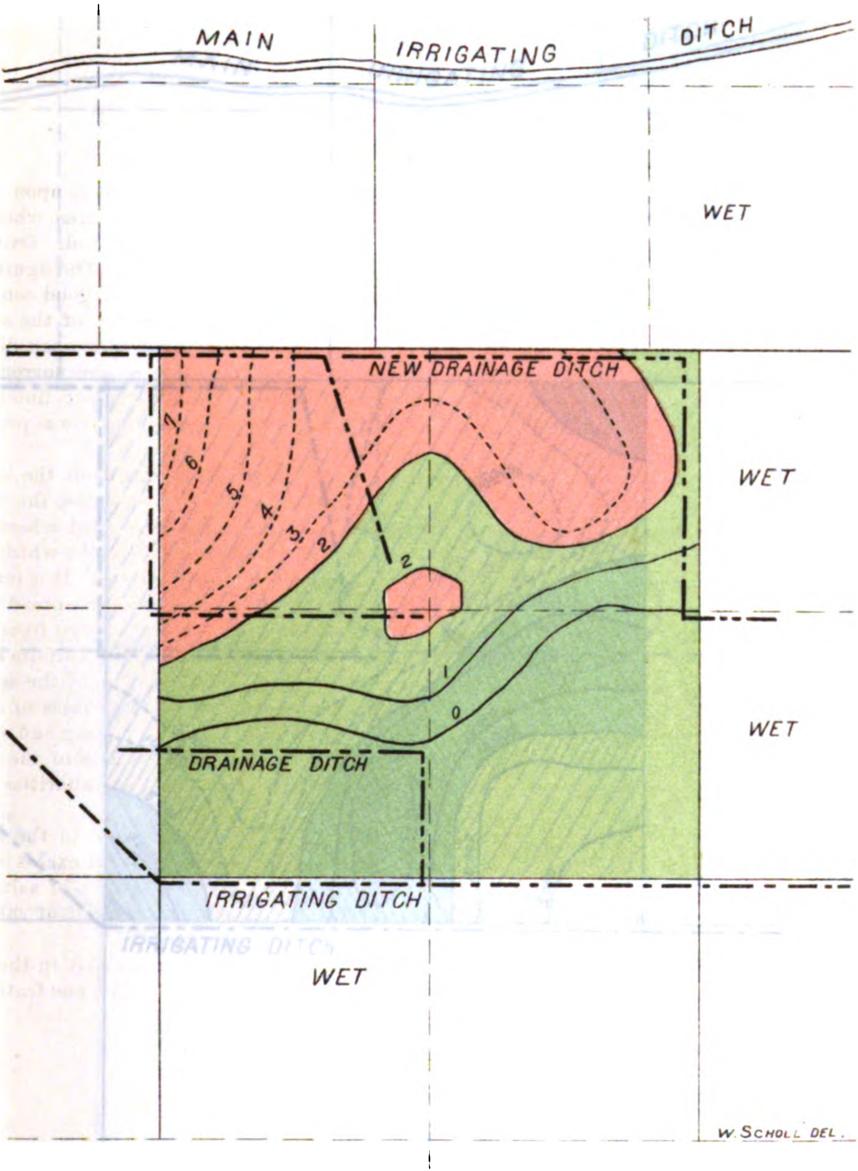
EXPLANATION OF PLATES.

PLATE X. This represents the depth to standing water on section 2, upon which alfalfa was gradually dying out. The green color represents the area where the depth to standing water is within 2 feet of the surface of the ground. Over this green area the alfalfa has died out and can no longer be grown. The figures and contour lines indicate the depth to water. The pink area is still in good condition for alfalfa. Much of the green area, especially in the lower section of the area, is a swamp, and efforts have been made to drain it in two places with open ditches. This accumulation of water is entirely due to overirrigation of the surrounding lands. Formerly this whole section of land was a valuable tract of fine alfalfa soil. Before irrigation was introduced into the valley standing water was probably not less than 25 or 30 feet from the surface.

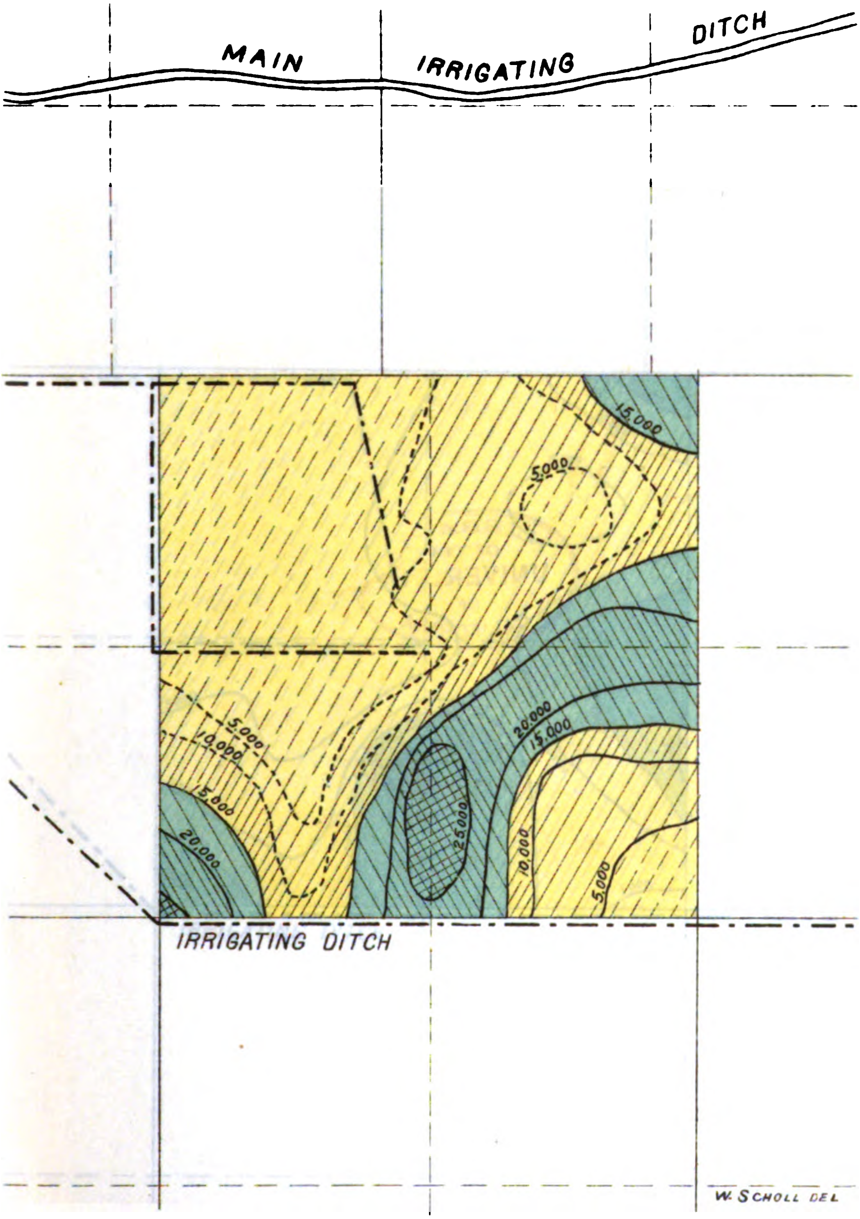
PLATE XI. This illustration shows the amount of soluble salts in the surface foot on section 2. The amount of salt is indicated by contour lines, the figures showing the amount of salt in pounds per acre. The pink color is used where there is at present no excess of salt, and the blue color indicates the area in which there is a large excess. The cross-hatching further brings out these areas. It is interesting to observe that the excessive salt content of the soil has not yet spread out so as to cover the whole of the swamp area of the section. It will be seen from Plate XIII that very nearly three-quarters of section 2 is rendered unfit for alfalfa or cultivated crops of any kind, as there is standing water within 2 feet of the surface. Hardly more than a third of this swamp area as yet contains an excess of alkali, but the records for the past few years show that the alkali is increasing and spreading rapidly. It is interesting to note, furthermore, the apparent path of the salt as it occurs in what appears to be a trough, probably due to some peculiarities in the structure of the soil.

PLATE XII. This represents the salt content in pounds per acre in the second foot of section 2. This is colored with yellow to indicate no present excess of salt, and with blue to indicate the areas containing an excessive amount of salt. The figures, contour lines, and hatching show clearly the actual amount of salt over different portions of the area.

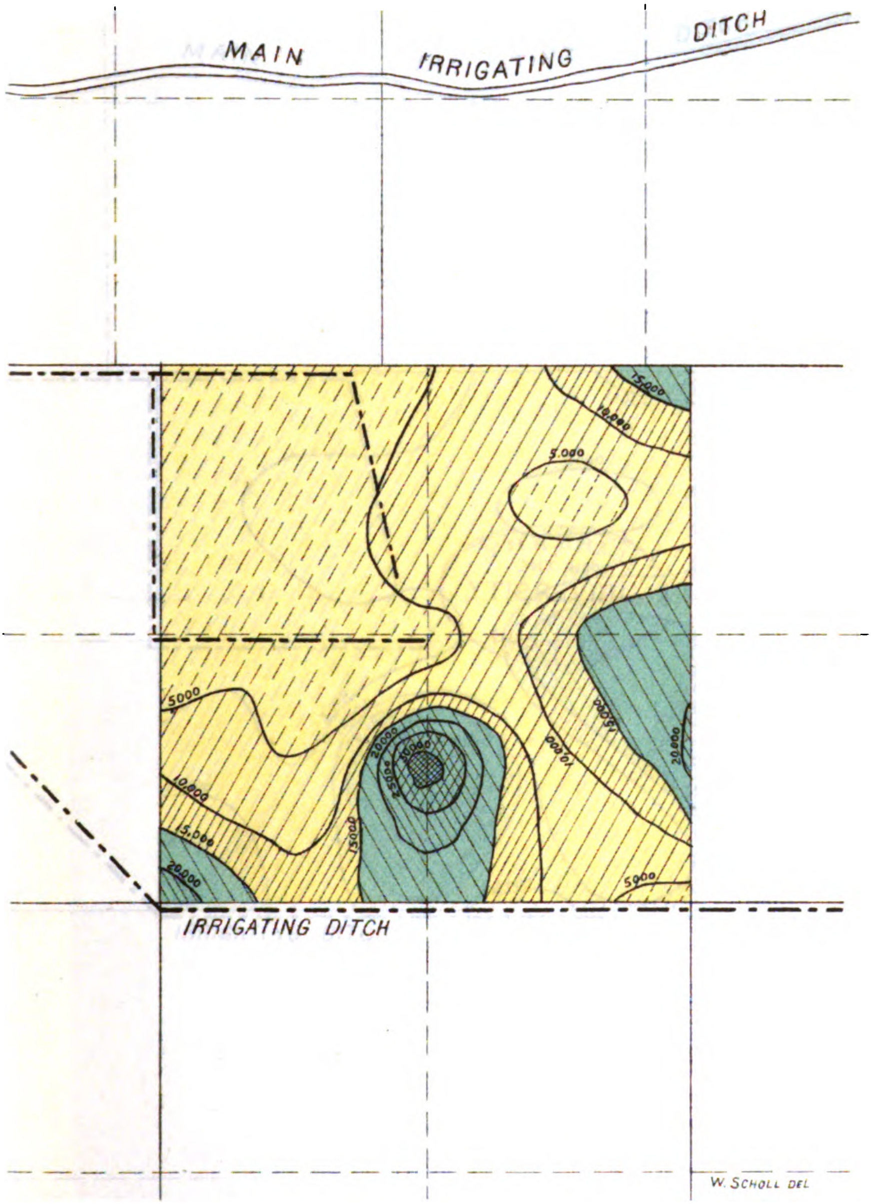
PLATE XIII illustrates the amount and distribution of soluble salt in the third foot in depth in section 2. The colors and hatching represent the same features as in the other plates.



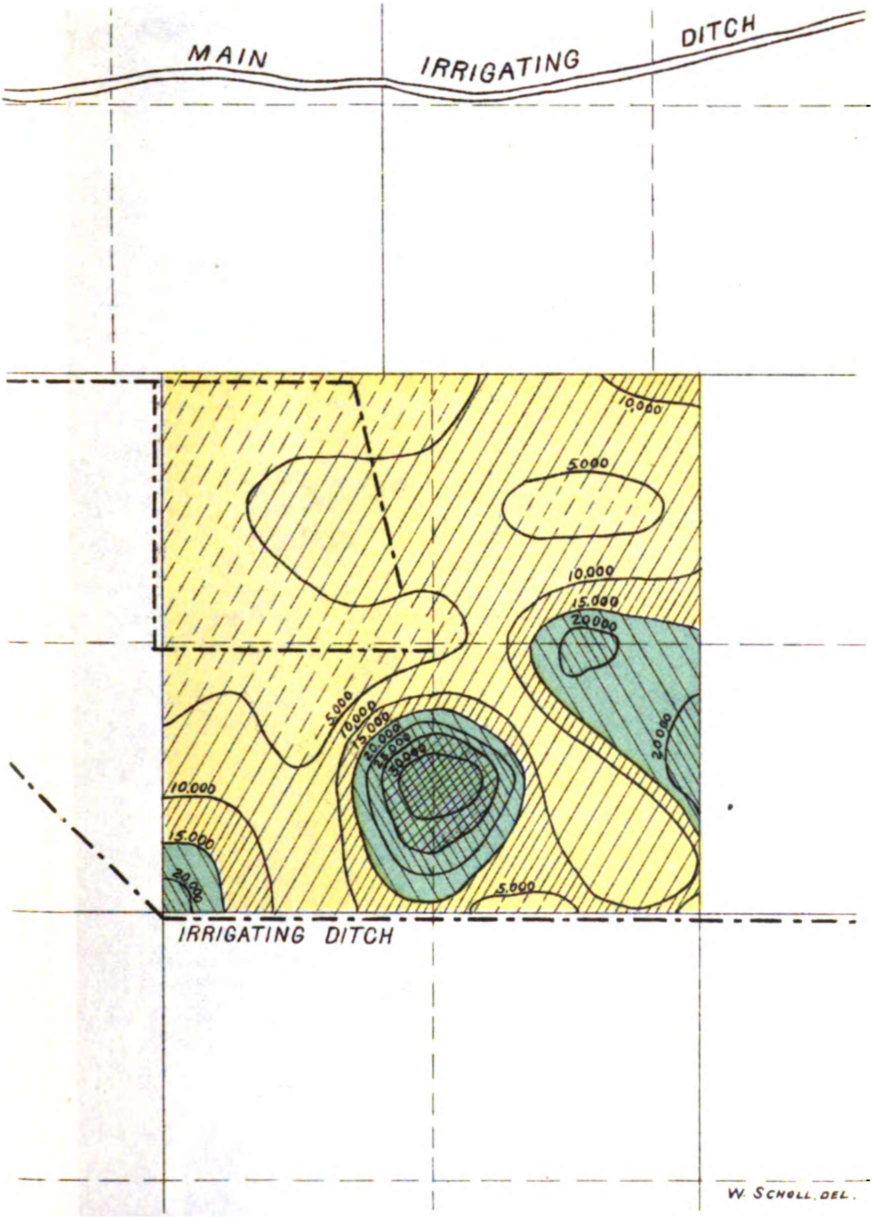
DEPTH IN FEET FROM SURFACE OF GROUND TO LEVEL OF STANDING WATER ON SEC. 2, T. 1 S., R. 25 E. THE GREEN AREA HAS STANDING WATER WITHIN 2 FEET OF THE SURFACE, AND ALFALFA WILL NO LONGER GROW HERE.



SOLUBLE SALT CONTENT OF THE TOP FOOT, SEC. 2, T. 1 S., R. 25 E. THE BLUE COLOR INDICATES AN EXCESS OF SALTS.



SOLUBLE SALT CONTENT OF THE SECOND FOOT, SEC. 2, T. 1 S., R. 25 E. THE BLUE COLOR INDICATES AN EXCESS OF SALTS.



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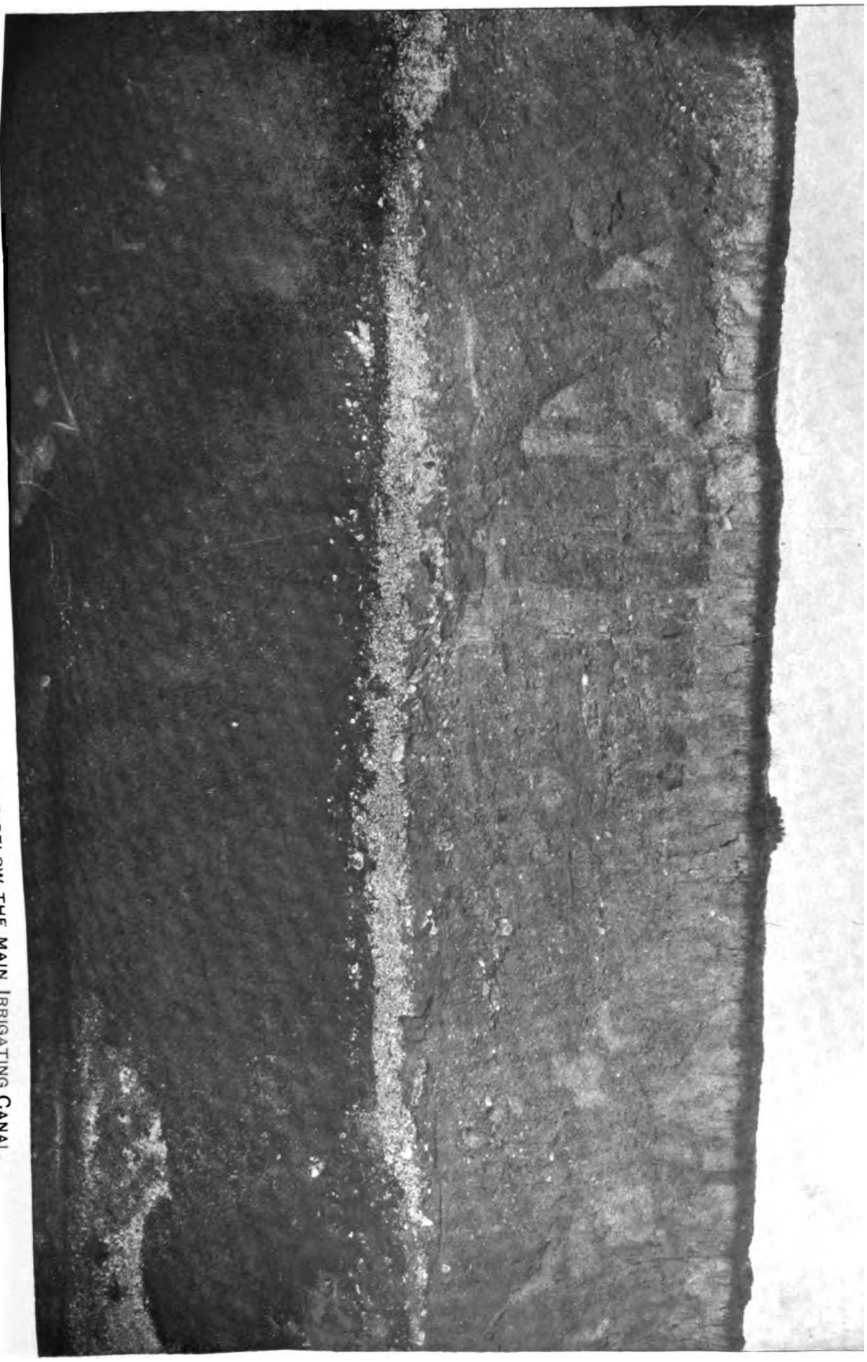
SOLUBLE SALT CONTENT OF THE THIRD FOOT, SEC. 2, T 1 S., R. 25 E. THE BLUE COLOR INDICATES AN EXCESS OF SALTS.



AN EXPOSURE IN CANYON CREEK, ABOUT ONE-FOURTH OF A MILE BELOW THE MAIN IRRIGATING CANAL.

A line of white alkali about halfway up the face of the canyon shows the line of gravel underlying most of these lands out of which water was flowing at the time the photograph was taken.

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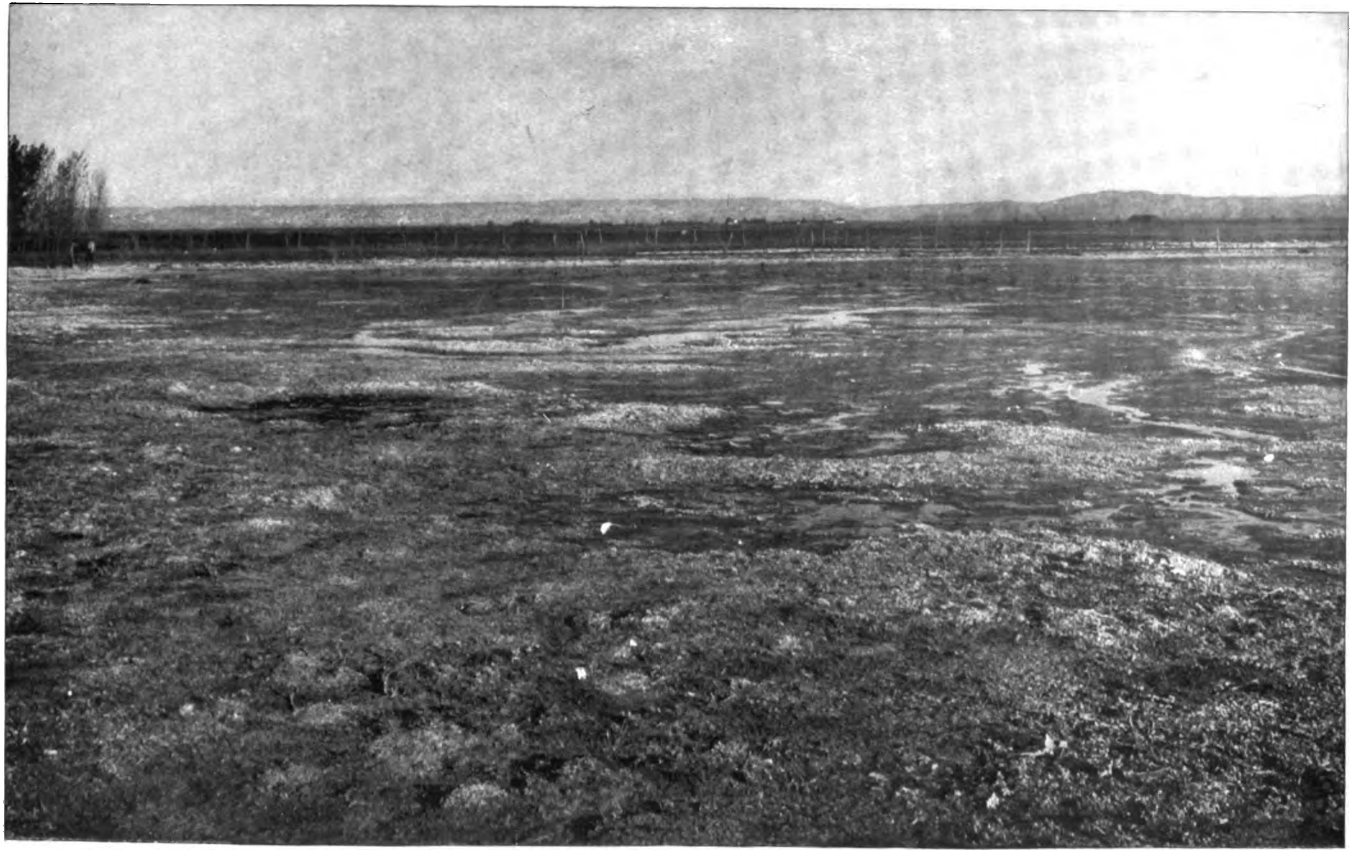


ALKALI FLAT ON SECTION 2, FORMERLY A FERTILE ALFALFA FIELD.

Lines B B, C C, and the small drainage ditch of Plates X, XI, and XII are in this area.

The value of such underground maps can hardly be overestimated to the owners of the land. It is seen just where the seepage waters and alkali salts are accumulating, from which direction they are coming, and just how drainage systems should be introduced to remove the trouble. They will show that some areas are quite safe for a number of years at any rate, and the maps will indicate other areas which will need careful attention or even energetic efforts in the prevention of or reclamation from damage.

SUMMARY OF THE INVESTIGATIONS AND CONCLUSIONS.

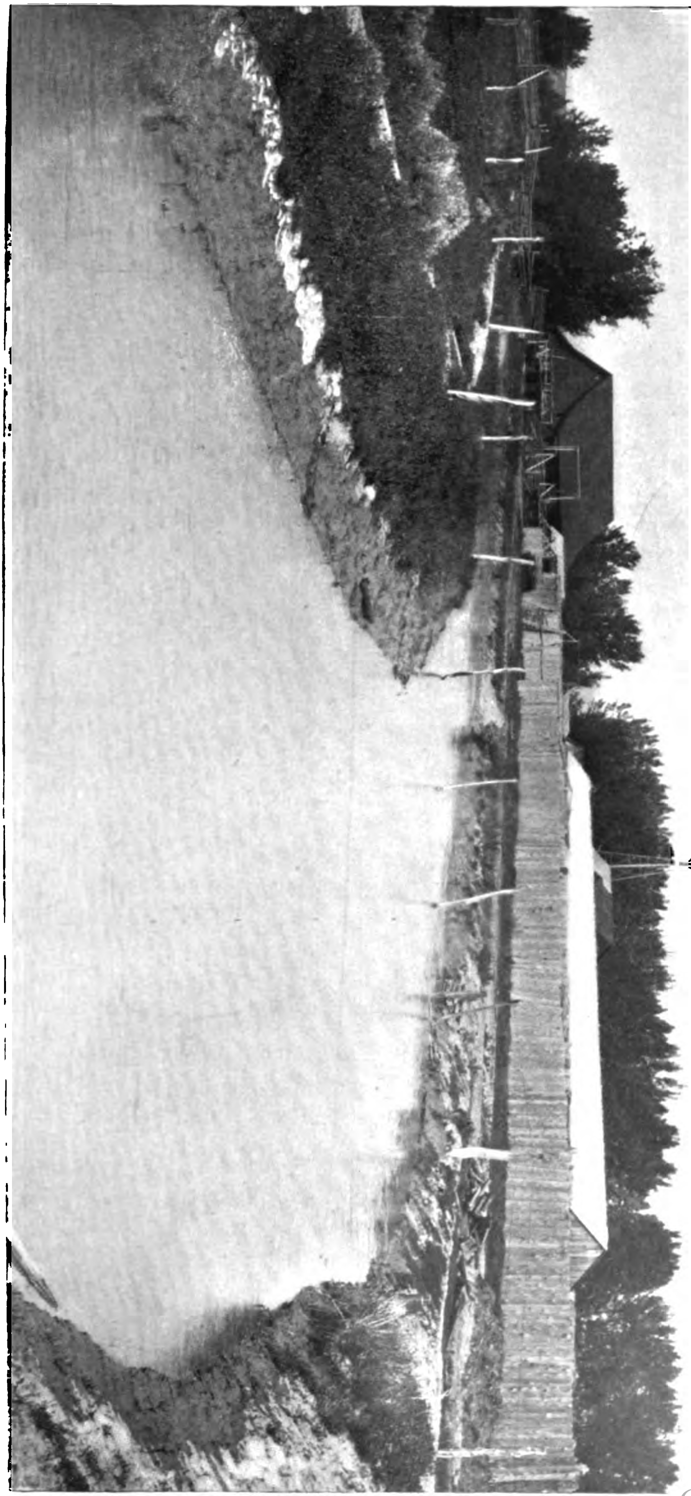
The results of these investigations show that the ultimate source of the alkali is in the sandstone, and particularly in the shale or slate rocks from which the soils have been derived. Before irrigation was introduced the salts were present in rather large amounts, but well distributed throughout the soil, and not in such large quantities as to be injurious to crops. The injury is due entirely to overirrigation, to the translocation and local accumulation of salts by means of seepage waters, and to the imperfect drainage facilities in the compact gumbo soils and the inability of the soils to remove the excess of salts and of seepage waters. The first trouble appears to be due to the seepage waters. This, of course, need not necessarily be so, but it appears to be the case in this locality. The open sandy lands, having better underdrainage, are not likely to be injured by a rise of salts except from an excessive application of water or in the low places in the path of the drainage system, especially when these are underlaid, as they are liable to be, by the heavy gumbo subsoils. The gumbo soil requires great care in cultivation, as it is easily ruined by the accumulation of seepage waters and the subsequent accumulation of salts. There are many areas in the valley, of course, which have still a low or moderate salt content which are probably safe for years to come. There are other areas in which the salts are now accumulating to such an extent as to render the future value of the land very uncertain, while there are still other areas which have gone beyond this stage, and what were once fertile tracts have been thrown out as barren flats. The investigations show, further, the very disturbing fact that the injury need not be due to a local application of water, but to the injudicious application of large quantities of it in remote localities and on neighboring farms over which the unfortunate person has no control and for the effects of which he has at present no redress.

The investigations point clearly to the natural methods of preventing this injury and of reclaiming the lands when once the injury has occurred. There is no question that the injury is due to the translocation and local accumulation of the salts which were formerly well distributed in the soils of the valley. Alkali has only been troublesome here after eight or ten years of irrigation. The trouble is always preceded by an accumulation of seepage waters, followed in a few years by the alkali incrustations on the surface of the land. This evidently points to the necessity of great care in the application of water in the methods of irrigation. This care must be exercised not only for the land which is being irrigated, but for the adjoining lands on lower levels. While a man can overirrigate a sandy tract with practical impunity to himself, he is likely to swamp his neighbor on a lower level. There are involved property rights, therefore, which will come to be recognized and which will have to be taken into consideration in any intelligent and safe system of irrigation.

Where the damage has been done, or where the conditions are so imminent that ultimate ruin can be foreseen, the logical method of reclamation is in providing adequate systems of drainage to carry off the excess of water and the accumulated salts. This is expensive, but it is the only thing in this case to hasten the slow processes of nature, which are entirely inadequate in the presence of the present methods of irrigation and of culture. Underdrainage is expensive, but it has amply repaid for the investment in other localities where land is worth no more than in the Yellowstone Valley. Any land which is worth $50 per acre could well afford to be taxed for underdrainage if it is necessary, as in many places in the Yellowstone Valley, to save the investment from utter annihilation. It may be too soon yet to urge an extensive system of underdrainage in the valley, but some small systems should certainly be introduced, if necessary by cooperation, for an object lesson when it is considered necessary and timely to protect against trouble or to reclaim lands already abandoned. The owners will then see that it is feasible to protect their lands and to reclaim, through underdrainage, those that are abandoned.

It has been pointed out already that there are some crops which can stand much larger percentages of alkali than others. It is quite possible that other valuable crops can be found or can be bred which will stand large quantities of alkali, but it is unfortunate, indeed, for a locality like the Yellowstone Valley, which is originally free from alkali, to accept such conditions resulting from their injudicious methods of irrigation and try to find crops which will thrive upon lands which have been unnecessarily injured.

It must not be assumed, however, that a thorough system of underdrainage relieves one from exercising care and judgment in applying water to the land. There is less immediate danger of ruining the land, to be sure, but there are two things to be considered, namely, that an excessive use of water means just so much loss to irrigation and so much less land which can be brought under the ditch, and also that in the removal of these salts by the flow of the seepage waters out through the drainage system large quantities of really valuable plant food are likely to be removed from the soil. The very accumulation of these soluble salts is due to the arid conditions of the climate. The great fertility of the soils results from the accumulation of these salts, and if we introduce



The Main Irrigating Canal; Water taken out of the Yellowstone River about 35 miles above the Place where this Illustration was taken.

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FEEDING OF SHEEP AND RANGE CATTLE DURING THE WINTER SEASON.

One of the important industries of the valley. It is principally for this winter feeding that the alfalfa and other forage and grain crops are grown.

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artificial drainage, which will tax the resources of the soil, we may remove in the course of a generation, or even in less time than this, the accumulated results of the changes of vast geologic ages in the disintegration of rocks. By overirrigation and underdrainage we may remove in a few years the very conditions which contribute to the wealth of the country in the fertility of the soil.

In taking up new land in the Yellowstone Valley the heavy gumbo soils should be underdrained at the time the first irrigation waters are applied to the land. Even if the system of underdrainage is not complete at the start, a sufficient amount of it should be put in to answer the purpose at the beginning, and so arranged that it can be extended and more laterals put in as time goes on and the necessity of it becomes apparent. It is too late to wait until the damage has been done, for the accumulation of salts themselves acts on the heavy gumbo soils and makes them more impervious to water and harder subsequently to drain. Great care must be taken in the application of water. As little as possible should be applied at each time, so that there shall be as little waste as possible to go off as seepage water. The surface then should be thoroughly cultivated, unless otherwise protected from evaporation by alfalfa or other close-growing crops, so as to reduce the loss of water from the surface to a minimum and prevent thereby the accumulation of salts at the surface.

The rise in the level of water in wells must be looked upon with uneasiness and guarded against with great care.

The conditions in the Yellowstone Valley are particularly simple, and the danger from the rise of salts may be easily controlled. These investigations show the cause of the trouble, the actual conditions over a small section of the valley, and point out the logical methods of preventing trouble and of redeeming the land after the trouble has come. The locality is fortunate indeed in having no great excess of alkali in the soils previous to irrigation, as occurs over such large areas in adjoining States. The question involved is a simple problem, well within the control of the intelligent land owners of the valley.

APPENDIX.

List of the borings, with the percentage of soluble salt content of each foot in depth.

(For location of borings, see map, fig. 1.)

	Location.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.
1	SW. cor. NE. ¼ sec. 4, T. 1 S., R. 26 E.	0.219	0.193	0.165	0.150	0.148	0.161	0.216								
11	Middle NE. ¼ sec. 4	.102	.513	.279	.167											
12	Middle NW. ¼ sec. 4	.323	.405	.411	.465											
13	Middle W. bound. NW. ¼ sec. 4	.442	.442	.493	.150	.241	.340	.377	0.330	0.296	0.496	0.534	0.282	0.218	0.207	0.192
14	Middle NE. ¼ sec. 5	.226	.704	.755	.785	.802										
15	¼ mi. S. center of N. bound. sec. 5	.037	.044													
16	⅛ mi. west (15), 100′ from draw	.031	.043													
17	Middle N. bound. sec. 5	.167	.904	.938	.809	.581										
18	Middle N. bound. NW. ¼ sec. 5	.050	.053	.160	.072	.074										
19	Bottom of draw, middle NW. ¼ sec. 5	.280	.874	.636												
20	Middle W. bound. NW. ¼ sec. 5	.047	.058	.217	.206	.165										
21	NE. cor. sec. 6, in alfalfa field	.166	.268	.289	.357											
22	Middle N. bound. NE. ¼ sec. 6	.050	.061	.084	.050	.048										
23	Middle N. bound. sec. 6	.250	.425	.285	.209											
24	Middle N. bound. NW. ¼ sec. 6	.350	.333	.253												
25	Middle N. bound. sec. 2	.144	.142	.113	.128	.138	.147	.170	.168	.170	.170	.185	.350	.172	.182	.165
26	Middle N. bound. NW. ¼ sec. 2	.046	.049	.052	.066	.097	.106	.128	.147	.112	.112	.056	.056	.058	.058	.058
27	NW. cor. sec. 2	.038	.045	.044	.051	.060	.051	.064	.070	.049	.049	.072	.072	.072	.072	.072
28	¼ mi. S. (27)	.033	.037	.028	.030	.048	.048	.048	.047	.047	.047	.044	.044	.044	.044	
29	¼ mi. S. (26)	.051	.106	.198	.175	.237	.240	.228	.237	.237	.237					
30	¼ mi. E. (29)	.191	.176	.167	.176	.152										
31	Middle sec. 2	.108	.074	.077	.083	.083	.162	.207								
32	SE. cor. sec. 2	.065	.082	.070	.057	.099										
33	¼ mi. W. (32)	.188	.237	.442	.464	.464	.307	.307	.246	.228						
34	Middle S. side sec. 2	.698	.519	.410	.322	.322	.274									
35	Middle S. side SW. ¼ sec. 2	.343	.371	.257	.629	.257	.257	.235								
36	SW. cor. sec. 2, 1st inch 1.023	.757	.714	.634	.612	.589	.187									
37	¼ mi. N. 36, marsh	.395	.283	.232												
38	Middle SW. ¼ sec. 2	.182	.168	.158												
39	SE. cor. sec. 5	.238	.804	.757	.750	.703	.706	.694								
40	Middle S. side sec 5	.354	.887	.234	.168	.200										
41	Middle S. half sec 5, ¼ mi. N. 40	1.028	.967	.853												
42	In cañon trib. to Alkali Creek	.020	.025	.019												
43	¼ mi. W. cemetery edge draw	.230	.542	.257												
44	SW. cor. NW. ¼ sec. 2	.045	.042	.045	.044	.043	.037	.077	.045	.075	.075	.082				
45	¼ mi. E. 44	.047	.030	.036	.031	.045	.045	.043	.043	.088	.038					
46	100 yds. S. 45	.054	.066	.112	.103	.109	.120	.138	.162	.154	.156					
46a	Dup. of 46, 2 ft. away	.074	.065	.064												
47	100 yds. S. 46, 100 yds. N. ditch	.155	.164	.177	.213	.191	.191	.225	.237	.237	.237	.212	.212	.252	.252	
48	5′ N. drainage ditch	.419	.253	.257	.238	.275	.267	.275	.337							

49	50 yds. W. center of flat, ¼ in. N. 34	.792	.920	.944	.792	.519	.519	.357	.357	.292						
50	Center SE. ¼ sec. 2	.260	.200	.168	.203	.198	.198									
51	¼ mi. N., S. bound. sec. 2, ¼ mi. E. 50	.238	.597	.679	.534	.464	.464	.310	.310							
52	Alfalfa dying NW. ¼ sec. 2	.229	.191	.182	.175	.159	.213									
53	¼ mi. E. (51)	.711	.410	.620	.464											
54	Center E. bound. sec. 2	.620	.534	.457	.457	.377	.377	.269	.269							
55	Middle E. bound. NE. ¼ sec. 2	.405	.225	.192	.195	.208	.208	.220	.220							
56	Center NE. ¼ sec. 2	.085	.102	.098	.139	.178	.250	.250								
57	Middle N. bound. NE. ¼ sec. 2	398	.310	.248	.230	.210	.210	.232								
58	NE. cor. sec. 2	.495	.573	.343	.243	.297										
59	S. bound, sec. 34, across road from boring 25	.213	.223	.243	.253	.297	.297									
60	200 yds. N. (59)	.161	.216	.242	.248	.220	.220	.235	.235	.216	.216					
61	200 yds. S. main ditch	.047	.044	.044												
62	100 ft. above main ditch	.033	.019	.045	.027	.032	.028	.019								
63	Center N. bound. sec. 3	.023	.050	.063	.032	.026	.034	.033	.048	.042	.042	.038	.046	.046	.044	.044
64	NE. cor. sec. 4; prairie	.042	.041	.035	.038	.045	.055	.156	.170	.238	.243	.205	.120	.163	.228	.178
65	Center N. bound. NW. ¼ sec. 1	.565	.487	.336												
66	Center N. bound. sec. 1	.644	.384	.310	.343											
67	¼ mi. S. of NE. cor. sec. 13	.019	.019	.087	.125	.164	.112	.078	.094	.083	.090					
68	Center Hesper farm, sec. 18	.039	.046	.032	.028	.018	.019	.035	.032	.025	.018	.019	.018	.017	.030	.100
69	¼ mi. E. (68)	.036	.027	.019	.050	.057	.047	.050	.071	.077	.075	.063				
70	Unirr. gumbo ¼ mi. S. Hesper farm	.035	.038	.054	.200	.333	.337	.253	.253	.282						
71	Beet patch, Hesper farm	.042	.077	.102	.065	.054	.052	.043								

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U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS.
MILTON WHITNEY, Chief.

SOIL SOLUTIONS:

THEIR NATURE AND FUNCTIONS, AND THE CLASSIFICATION OF ALKALI LANDS.

BY

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SOIL CHEMIST, DIVISION OF SOILS.
[COOPERATING WITH THE DIVISION OF CHEMISTRY.]

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Soils,
Washington, D. C., March 20, 1901.

Sir: I have the honor to transmit herewith the manuscript of a technical paper by Dr. Frank K. Cameron, Soil Chemist of this Division, on the nature and function of soil solutions. In accordance with the general policy of the Department, this has been submitted to and has received the indorsement of Dr. H. W. Wiley, Chief Chemist.

I recommend that this paper be published as Bulletin No. 17 of this Division.

Respectfully,

Milton Whitney,
Chief of Division.

Hon. James Wilson,
Secretary of Agriculture.

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SOIL SOLUTIONS: THEIR NATURE AND FUNCTIONS AND THE CLASSIFICATION OF ALKALI SOILS.

By Frank K. Cameron.

NATURE AND FUNCTION OF SOIL SOLUTIONS.

MUTUAL EFFECT OF ELECTROLYTES.

Soil solutions from which plants draw their food are for the most part aqueous solutions of the mineral components of the soil. Other components, organic generally, are found to a greater or less amount in these solutions, but those substances in the solution, inorganic or organic, which furnish materials for the sustenance of vegetation belong almost entirely to that class of chemical compounds known as electrolytes. It is a characteristic of such compounds that in aqueous solution they impart to the solution the power of conducting the electric current, and from this fact they take their name. This power of conducting electricity when they are dissolved in water is practically confined to those substances known as acids, bases, or salts, which last may be considered as formed by the combination of acids with bases. To one of these three classes may be assigned, almost without exception, all the mineral components and many of the organic components found in soils. A study of the soil, therefore, is a study of a heterogeneous system composed of a number of components, mainly electrolytes, in contact with an aqueous solution of themselves. It is true that the actual amount of some of these components in the solution may be quite small, but to some extent at least every one of the components is dissolved when in contact with the solution. The general considerations involved in such a study have been presented at length in a recent publication of the Division.[1] They can not be given in detail here, but some of the fundamental ideas involved will be repeated, and it will be shown in what manner they can serve to coordinate and explain observations already made upon soil phenomena, and, more important still, how they may indicate many lines of investigation which can not fail to yield a rich harvest both to science as such and to economic husbandry.

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[1] Report 64, United States Department of Agriculture.

For purposes of illustration let it be supposed that one of the soil components is calcium silicate ($CaSiO_3$), and for the moment let the further supposition be made that it does not itself react with water; that is to say, does not form new compounds on going into solution. If this substance come in contact with water some of it will dissolve or diffuse through the water until at length a definite amount of it, depending upon the temperature and the absolute amount of the water, will be taken up and held in solution. The ratio of the amount dissolved to the amount of water is called the solubility and is a constant, characteristic of the substance for a definite temperature. It is now a generally accepted hypothesis that the part of the substance which has gone into solution (called for convenience the *solute*), partially breaks up or separates in the act of dissolving and these separated parts called *ions*, bear definite charges of electricity associated with them in some manner. In the nomenclature of chemistry this fact would be expressed thus:

$$CaSiO_3 \rightleftarrows \overset{+}{Ca} + \overset{-}{SiO_3}$$

that is to say, that when a state of equilibrium has come about there would be present in the solution some calcium silicate as such and a perfectly definite amount of the ion, calcium, bearing a charge of electricity, positive in sign, and a chemically equivalent amount of the ion SiO_3, bearing an equal amount of electricity but negative in sign. The solution will of course remain saturated with respect to the undissociated calcium silicate, for enough of the material in the solid phase and in contact with the solution will continue to go into solution until it is saturated with respect to it. This does not imply, however, that the solution is necessarily saturated with respect to any of the possible ions which may be formed.

It is due to the presence of these ions bearing their charges that the solution of an electrolyte will conduct, for if such a solution be made part of a closed circuit there will be a tendency for the positively charged ions to move toward the negative electrode and a corresponding tendency for the negatively charged ions to accumulate at the positively charged pole. At the poles the ions will give up their electric charges, but on losing their charges the ions cease to exist as such, and either reunite to form the undissociated electrolyte, or, more commonly, take part in secondary reactions with the water. The disappearance of the discharged ions disturbs the equilibrium between the undissociated electrolyte and its ions and more of it will dissociate. The process is therefore continuous, and furnishes a vehicle for the transferrence of electrical energy through the solution.

The extent to which ions will be formed, or, as it is conventionally phrased, the amount of electrolytic dissociation, is a perfectly definite quantity for each individual electrolyte. It is in fact a characteristic constant, but depends upon the concentration and temperature.

It should be noted that the ions themselves have definite characteristic properties, and these properties may be, and generally are, very different from what they would be if the ions lost their associated or accompanying electrical charges and became merely elements or groups of elements. Further, it has been most amply demonstrated that those chemical properties with which we most commonly have to deal in solutions of electrolytes are those of the ions which the solution may contain. Very much less seldom are we concerned directly with undissociated portions of the electrolytes. Studies of such solutions become, therefore, mainly studies of solutions of ions.

Suppose another electrolyte, such as potassium nitrate, be dissolved in the solution of calcium silicate under consideration. It will also dissociate partly, thus:

$$KNO_3 \rightleftarrows \overset{+}{K} + \overline{NO}_3$$

and there will be in the solution undissociated $CaSiO_3$, ions $\overset{+}{Ca}$, ions $\overline{SiO}_3$, undissociated KNO_3, ions $\overset{+}{K}$, and ions $\overline{NO}_3$. But the ions $\overset{+}{Ca}$ and ions $\overline{NO}_3$ can and will unite to some extent to form undissociated $Ca(NO_3)_2$ calcium nitrate. In the same manner ions $\overset{+}{K}$ and ions $Si\overset{=}{O}_3$ will unite to some extent to form K_2SiO_3 or undissociated potassium silicate. But the calcium ions and SiO_3 ions withdrawn to form calcium nitrate and potassium silicate respectively will disturb the equilibrium between the undissociated and dissociated calcium silicate. More of it will dissociate to supply the places of the withdrawn ions, and this will in turn disturb the equilibrium between the dissolved but undissociated calcium silicate and the substance in contact with the solution, but in the solid phase. More of this latter will dissolve to restore the equilibrium, and in consequence one of the most striking results of the addition of the second electrolyte, which does not furnish an ion in common with those already in the solution, is to increase the solubility of the first electrolyte. It is obvious that just as the presence of the potassium nitrate increases the dissociation of the calcium silicate, just so the calcium silicate causes an increase in the dissociation of the potassium nitrate; that is, they exert a mutual influence on one another and of the same kind.

On the other hand, suppose calcium nitrate to be the second electrolyte introduced into the solution. It would dissociate thus:

$$CaNO_3 \rightleftarrows \overset{+}{Ca} + \overline{NO}_3$$

and more calcium ions would be added to the solution. But the addition of more calcium ions would disturb the equilibrium between the calcium ions and the dissociated calcium silicate. To restore the equilibrium some of the calcium ions would unite with the SiO_3 ions to form undissociated calcium silicate, the solution would become supersaturated with respect to this compound, and some of it would in consequence separate in the solid phase and be withdrawn from the solution. In other words, the addition of a second electrolyte which will furnish an ion the same as one of those already in the solution will diminish the solubility of the first electrolyte. Again, it is scarcely necessary to say the reaction between the two electrolytes is mutual in effect.

To summarize briefly, two or more electrolytes brought into solution simultaneously do, and must of necessity, affect one another. If they furnish no ion in common, they increase each other's dissociation (though not necessarily increasing the actual *number of ions* in solution) and consequently their respective solubilities. If, however, a common ion is yielded, the dissociation of the substances from which it comes is decreased, and consequently their respective solubilities are lessened. These effects are in all cases mutual.

It has been stated above that the amount of dissociation, other things—temperature, concentration, etc.,—being equal, is a constant for each electrolyte and characteristic of it. It should now be added that different electrolytes vary widely in this respect. Those electrolytes which dissociate very readily, yielding a relatively large number of ions, are called strong and, conversely, those electrolytes which yield only a relatively small proportion of ions are designated weak. In the case of an acid or base the extent to which it dissociates and thus yields chemically active ions is taken as the measure of its strength. This factor of "strength" or dissociating power must be considered in all studies of the mutual effects of one electrolyte upon another, for it is plain that such effects as have been brought out above would be relatively more pronounced with the weaker electrolyte. It does not necessarily follow that the weakest electrolyte would be the first to separate in the solid phase or precipitate from a solution, however, for the absolute solubility of the undissociated salt is a factor, and as to this it is utterly impossible to predicate anything at present beyond empirically determined data. For instance, if ammonium sulphate and calcium nitrate be brought together calcium sulphate will precipitate because undissociated calcium sulphate is less soluble than any other compound that could be formed from the resulting ions. But in so far as it is soluble it is highly dissociated, much more so, for instance, than the very soluble but comparatively weak electrolyte, ammonium nitrate, which would be formed simultaneously with it.

The electrolytes which have been taken for purposes of illustration in the explanations just given are of comparatively simple composition, but exactly the same principles apply to even the most complex silicates or organic compounds, provided they be electrolytes.

It will thus be seen that the soil components have a very decided influence on the solubility of one another, and that a most marked effect may be expected from the artificial addition of another electrolyte. From these considerations it is readily apparent that the rôle of a mineral fertilizer is at least twofold. It may furnish plant nutriment itself to the soil solution, but it may have as great an effect in increasing or diminishing the solubility of the original soil components. That this effect may be very great relatively will be seen by citing a few instances.

Kippenberger is quoted as having found the solubility of calcium carbonate increased about threefold by the addition of sodium chloride. It has been shown in the laboratory of this Division that the solubility of calcium sulphate in the form of gypsum can be increased about four times by the addition of sodium chloride. The solubility of magnesium carbonate can probably be doubled by the addition of sodium chloride to the solution. Not many quantitative measurements of this kind have been made as yet, but there is very good reason to believe that even more striking increases of solubility of soil components may be brought about by the addition of mineral fertilizers, and investigations along these lines will undoubtedly be of the greatest value to agriculture and to geology as well as to chemistry.

The anomalous results often noted by investigators, that the addition of one plant nutrient to the soil will frequently result in the crop removing unexpectedly large amounts of another nutrient, are readily explained from this point of view, as well as the sometimes detrimental effect of the addition of substances which themselves are known to be harmless.

The electrolytes which form the soil components are mainly silicates, alumino-silicates, aluminates, ferrates, carbonates, etc. They have a marked common characteristic in that they are all salts of weak acids.

HYDROLYSIS.

It is a well-established fact that when an electrolyte dissolves in water a reaction takes place to some extent between the electrolyte and the water, for water is itself an electrolyte, although a very weak one. For instance, sodium chloride will react with water, as thus indicated:

$$NaCl + HOH \rightleftarrows NaOH + HCl$$

But all of these substances are strong electrolytes and largely dissociated, excepting only the water. The equilibrium constant for water is very low indeed, and the hydroxyl ions from the sodium hydroxide and the hydrogen ions from the hydrochloric acid will reunite to form water, so that the extent to which this reaction will take place is very small indeed—too small to be detected by the usual means at our disposal. That it does take place to some extent, even with comparatively strong electrolytes, can be readily recognized in some cases. For instance, magnesium chloride reacts with water to form to a small extent magnesium hydroxide and hydrochloric acid, and on evaporating the solution to dryness a very small portion of the volatile hydrochloric acid will be distilled away.[1]

By repeating the process a few times the residue will be found decidedly alkaline. In a quite analogous manner, when calcium chloride is thoroughly dehydrated by fusion the residue always contains some little calcium oxide, the hydrolized hydrochloric acid having been volatilized.

When the case of an electrolyte consisting of a weak base united to a strong acid, or, vice versa, a strong base united to a weak acid, is considered, this reaction with water, or hydrolysis, becomes much more marked. For example, in the case of nicotine sulphate in aqueous solution it is well known that the solution can not be concentrated by evaporation near the boiling point without serious loss of the nicotine, and this in fact is a serious annoyance in the estimation of this substance. The explanation is quite obvious. The nicotine being a very weak base, its salts are considerably hydrolized in the water solution with the formation of free nicotine, which is readily volatilized and distilled off, especially with steam.[2] On the other hand, the hydrolysis of sodium carbonate, in which a strong base is in combination with a very weak acid, is quite familiar to every one. The alkaline reaction of solutions of calcium or magnesium carbonate is another striking and familiar instance. The efficiency of soap is probably to be explained in a great measure in the same way. Soaps in general consist of organic salts of sodium or potassium, in which strong bases are combined with relatively weak acids, and therefore are more or less hydrolized, rendering the base free to act upon the skin or other substance to be washed.

It has been shown by several investigators, notably Clarke,[3] W. B. and R. E. Rogers[4] among others, that a great many minerals dissolve quite rapidly in pure water, although the absolute amount which goes into solution is not perhaps very large, and that when the minerals are silicates or alumino-silicates of the alkali bases or alkaline earths the solutions are always decidedly alkaline. Here is presented a very beautiful instance of hydrolysis, depending on the fact that the bases involved—potassium, calcium, etc.—are united to very weak acids, and the resulting solution is in fact a solution in part of the free bases. The amount of base thus set free is of course dependent mainly upon the factors, the amount of the solubility of the undissociated substances, and the strength of the acid compound in the solutions, together with the strength of the particular base involved. The solubility of the undissociated mineral is fortunately seldom of any considerable magnitude. The acid formed by the hydrolysis is usually quite unstable itself and readily breaks down, with the partial separation of the silicon in the solid phase as some form of silica, crystalline or amorphous. The aluminum or iron, etc., which is so frequently a constituent of the acid radical, also yields very insoluble compounds, and is precipitated in such forms that if the solubility of the original mineral was at all considerable it seems probable that the basic constituents would soon be leached away from the surface soils.

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[1] Mr. Atherton Seidell has verified this statement for me by a careful experiment which yielded very decided results. The solution of magnesium chloride was carried to dryness on the steam bath, taken up with water, and again carried to dryness. After repeating the process some three or four times the solution gave a markedly alkaline reaction with phenolphthalein.

[2] At my request Mr. Seidell repeatedly evaporated a solution of ammonium sulphate to dryness on the water bath, the residue being again taken up each time with distilled water. After a few repetitions of the process, the solution of the substance, which had originally appeared to be perfectly neutral, gave a decided acid reaction with methyl-orange, Congo red, or litmus. Undoubtedly the weak base ammonium, combined with the strong sulphuric acid, was considerably hydrolized and volatilized, even in the presence of an excess of acid.

[3] Jour. Am. Chem. Soc., **20**, 739 (1898).

[4] Am. Jour. Arts and Sciences (1848).

This action of water, or hydrolysis, must be a potent factor, not only in making mineral constituents of soils available for plant nutrition, but in the formation of the soils themselves, by breaking down or weathering the rocks from which the soil components are derived. In so far as the addition of other readily soluble electrolytes assist in rendering soluble the mineral components of the soil, as has been indicated above, they may be regarded as assisting in the weathering or ultimate decomposition of these mineral components. It seems worth while to lay stress upon this point of view, for it suggests interesting lines of work for the general geologist, as well as for the soil investigator, and affords a reasonable explanation of many facts hitherto accounted for in a most unsatisfactory manner. For example, it is conventional in the text books to explain the formation of kaolin from feldspar by the action of carbonic acid on the latter mineral. It has been a source of trouble to many students to see how a weak, volatile, and slightly soluble acid like carbonic acid could so readily affect such a stable compound. It is much more reasonable to suppose that in the feldspar there is a very strong base-forming element—potassium—in combination with a very weak acid-forming radical, and that, although but slightly soluble, the compound does dissolve to some extent and is considerably hydrolized. The hydrolized base, being very soluble, is then readily leached away and by absorption of carbon dioxide forms the carbonate as the result of a secondary or subsequent reaction. The hydrolized free acid, being a very unstable compound, breaks down at once, yielding the two very slightly soluble substances, kaolin and silica. Many such illustrations might be cited, but space forbids.

RÔLE OF IRON IN THE SOIL.

Particularly interesting is the rôle of iron, when studied from this point of view. It is both a weak base-forming element and a weak acid-forming element, and, in consequence, its salts are very readily hydrolized. The acid reaction of ferrous sulphate solutions, due to the formation of sulphuric acid by hydrolysis of the salt, is quite familiar to every one. How far we may have to deal with ferrous iron in the soil is still an undetermined matter. It is generally supposed to be of very small importance, but it should be remembered in this connection that there is good reason for supposing that ferrous iron can and does often replace magnesia or lime in certain minerals, and that if these minerals come into contact with the soil solutions there must be some ferrous iron brought into the solution. But ferrous iron, even in the presence of considerable quantities of free acid, is quite rapidly oxidized to the ferric condition, and it is generally supposed that on the surface of the soil grains, where the solution is taking place, the iron has been oxidized to the ferric condition.[1] The salts of ferric iron are as a rule less soluble than the salts of ferrous iron, so that the hydrolized ferrous iron is quickly oxidized to ferric hydrates and in this form precipitated, more or less coating and covering the soil grains and protecting them from the further solvent action of the soil solutions. But the ground waters generally carry in solution considerable carbon dioxide, which unites to some extent with the ferric hydrates forming the carbonate or some one or more of the rather indefinite compounds classed under the head of hydrated carbonates. These substances are decidedly more soluble in water, especially when the water is kept saturated with carbon dioxide, whereby they are prevented from decomposing and giving up part of the carbon dioxide contained in them. They are rather unstable compounds, readily breaking down under normal conditions. If by aeration, or in some other manner, the water loses some of its dissolved carbon dioxide, these compounds, being unstable, break down to a greater or less extent and give off some of their carbonic acid, so that the amount of carbon dioxide dissolved as such will be increased and the equilibrium of the system restored. At the same time some of the iron is reprecipitated as the hydrate or hydrate carrying more or less of the carbonate. This process is well exemplified in the case of a well water taken from near Hyattsville, Prince George County, Md., and examined recently in this laboratory. This water when first obtained yielded on analysis 9.44 parts Fe_2O_3 per hundred thousand parts of water, but on standing for twenty-four hours a dense precipitate was formed and an analysis of the filtered water showed but 0.24 part of Fe_2O_3 per hundred thousand. An examination of the precipitate showed it to be composed entirely of hydrate or hydrated carbonate of iron. This water undoubtedly may be regarded as an extreme case, but it is cited here to show that large amounts of iron can be, and probably are, transported in this way. If the process of the separation of the iron compounds be somewhat slow it will precipitate in a more compact or crystalline form. We thus have an explanation of the formation of the sometimes large masses of iron stone, conglomerate, or hardpan which is often found in our fields at various depths, more or less shallow. The iron compound separates from the solution at the particular depth at which it is found because at that point aeration has been sufficient to lower the partial pressure of the carbon dioxide in the atmosphere in contact with the solution, allowing this latter substance to escape, with the simultaneous reprecipitation of the iron compound which cements together the material in which the precipitation takes place. Or it may happen that the solution passes from a fine-textured soil in which the interstitial spaces between the soil grains are very completely filled by the solution, to a coarser-grained soil with larger spaces, which the solution does not completely fill, and into which therefore some of the dissolved carbon dioxide can escape in the gaseous phase. It is interesting to note in this connection that the iron hardpan is frequently found at or near the surface of contact of deposits of markedly different texture.

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[1] This is certainly not the case in some soils, especially in the more arid regions of the West, as a microscopic examination will show.

As interesting and important as are the functions of iron just noted, it should be borne in mind that it is as an acid-forming element that trivalent iron is found in its most stable compounds; and that in all probability an important rôle which it plays in the soil is in the form of ferrates which help to conserve the bases resulting from the decomposition and decay of more complex compounds.

Another function of iron, in which it appears as a base, is worthy of earnest consideration. It is generally held that it plays an important rôle in holding in combination with it the phosphoric acid in the very insoluble compound, iron phosphate. This idea seems entirely reasonable, for, besides the very limited solubility of the substance itself, there is but little assistance to be expected from the hydrolizing effect of water. Both the acid and base are weak, and their corresponding hydrates would be but very little dissociated. Nevertheless, the action of another electrolyte, especially if made up of a strong base and acid, would have a marked effect in increasing its solubility. For instance, let it be supposed that potassium nitrate be added to a soil containing iron phosphates. If the reaction were undisturbed by other influences, then a condition of equilibrium would result which could be represented by the following expression:

$$FePO_4 + KNO_3 \rightleftarrows Fe(NO_3)_3 + K_3PO_4$$

But the ferric nitrate would promptly be more or less hydrolized, precipitating ferric hydrate and setting free nitric acid. At the same time the normal potassium phosphate, consisting of a very strong base with a rather weak acid, would also be partially hydrolized, forming a secondary or primary phosphate. Probably the hydrolysis would be more extensive in the case of the iron salt, so that the resulting solution would be acid, and this would have to be taken into account in predicting the nature of the alkali phosphates and other substances formed. Nevertheless all these substances would be formed and would exist in the resulting solution, and it would be entirely justifiable to say in this sense that the potassium nitrate had partially converted the insoluble iron phosphate into the readily soluble alkali phosphate, and thus made the phosphoric acid available to the plants. The iron may be justly regarded as of the greatest value in conserving the phosphoric acid, holding it so that it may be taken out gradually, under proper conditions, so that this exceedingly valuable asset in fertility will not be quickly leached out or otherwise removed from the soil. It is not surprising, then, that it has been noted in agricultural practice that the addition of a potassium fertilizer has improved the condition of the soil in regard to phosphates and rendered ambiguous the results of the analyses of the crops.

RÔLE OF CALCIUM IN THE SOIL.

Rather different, however, is the mechanism of the action of lime on the phosphoric acid held by the iron. If the calcium be in the form of a strong electrolyte the action will be analogous to that with potassium nitrate; but if it be added in the form of oxide, hydrate, or carbonate, it is fair to assume, in view of what is known as to the hydrolytic action of water, that to all intents and purposes it will be the hydrate to which attention should be directed. The problem then becomes one of the distribution of the phosphoric acid between the two bases—calcium and iron. The features of the general problem can not be discussed in detail here. A very clear statement of an analogous case will be found elsewhere.[1] It will be sufficient to say that the acid will be distributed between the bases, and that a quantitative expression can be given to the ratio in which the distribution will take place. The problem as it is presented to us is much more difficult than any in which quantitative measurements have actually been made, for the solutions are in contact with the solid phases; furthermore, questions of relative and absolute solubility, for which no accurate data are available, enter into consideration. In general terms, the distribution will take place in favor of the stronger electrolyte.

In the case under consideration the effect of liming may be expected to render the ferric phosphate more soluble by converting a part of it into lime phosphate. In a similar manner liming would react with a potash silicate—for example, the acid being distributed between the two bases according to their relative strengths or ionization constants, and the liberated potash becoming, in consequence, more readily available because more soluble. The more or less complete replacement of potash by lime, when added to the soil, has long been known. The problem it presents for study has, however, often been complicated by confusing it with the question of the existence or nonexistence of readily soluble hydrous silicates or zeolites in the soil. Whether or not there be zeolites formed in the soil is really foreign to the problem, for it is evident that if any potassium silicates be in the soil the potash must be released to some extent by the lime.

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[1] Nernst, Theoretical Chemistry (translated by Palmer), p. 432 (1895). See also, Arrhenius, Zeit. für phys. Chem., **5**, 1 (1890).

SOME POSSIBLE FUNCTIONS OF HYDROUS SILICATES.

On the other hand, no satisfactory evidence has been brought forward to show that zeolites or other hydrous silicates may not be formed in the soil beyond the fact that they have not been found there in well-defined crystalline masses. *A priori* one would rather expect that such substances might be formed, for, compared with other silicates they are readily soluble, and the constituent materials are at hand, and, as far as we know, there is no reason to suppose that synthetic processes should not be taking place in the soil, as well as destructive ones. Even if formed only in subsoils or lower depths, the minerals might be expected to be brought into the upper soil layers in solution. Wöhler[1] long since showed that apophyllite could be dissolved in water and recrystallized unchanged from its solution as any ordinary salt. There is good reason to suppose that other minerals of this class would behave in an analogous manner.[2]

The researches of Tammann[3] have shown very conclusively that for some of the zeolites the water they contain is not held as ordinary water of crystallization, but that, as a matter of fact, these minerals are solid solutions in which we may regard the silicates as the solvent and the water as the solute or dissolved substance, and that between certain limits these minerals may dissolve any amount of water, depending, of course, upon the temperature and the partial pressure of the water vapor in the atmosphere in contact with the solid solution. It would seem probable, therefore, that one of the functions of such substances, if they do exist in the soil, is to conserve the moisture, becoming saturated with water, when there is an excess of this agent present, and gradually giving it up in times of drought, so that it can become available to plant growth.

Many investigations have shown that the bases of these hydrous silicates are readily replaceable, in part at least, and it has long been believed that the addition of lime to the soil caused a redistribution of the acid radicles of these hydrous silicates, with a consequent separation of a part of the potassium they held in a more soluble form. Recent investigations of Clarke and Steiger,[1] which show that at comparatively high temperatures the bases in these minerals may be partially replaced by ammonium, also indicate that the replacement may go on more slowly or to a lesser extent at ordinary temperatures.

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[1] Jahresber, Liebig und Kopp, p. 1262 (1847–48).

[2] The Rogers (loc. cit.) found this to be the case.

[3] Wied. Ann. 63, 16 (1897); Zeit. anorg. Chem. 15, 318 (1897).

But, further, the very beautiful investigations of Friedel[2] showed that just as these minerals could take up water, in precisely the same way they could take up ammonia. In fact, the water, at that time supposed to be water of crystallization, could be partly replaced by ammonia, so that it seems quite probable that another function of these compounds is to conserve ammonia in the soil.

It is true that the ideas just advanced must be regarded as speculative, but they are presented here as showing that the long-existing controversy as to the existence of zeolites or other hydrous silicates in the soil has a real importance, both scientific and economic.

ACIDITY OF SOILS.

From what has been said above the impression might be obtained that soil solutions would generally be alkaline, since the acids are nearly all weak, often unstable, breaking down with the separation of insoluble products, and the bases to which they are combined are strong. But, as a matter of fact, we know that soils are for the most part somewhat acid in character. It should be remembered, however, that soil solutions may generally be regarded as culture solutions for various organisms, which feed upon and break down the complicated organic matters contained in the soil, an almost invariable accompaniment of these processes being the formation of acids, sometimes organic, sometimes mineral, as in the case of the nitrifying organisms. The purely oxidation processes taking place in the organic matter must further yield considerable amounts of organic acid. The excretions from plant roots, which are, in the main, acid, are generally supposed to be important factors in this regard. These acids, of course, serve, in part, to neutralize the bases.

RÔLE OF CARBON DIOXIDE.

A very important rôle in this respect is, in all probability, played by carbonic acid or carbon dioxide dissolved in the solutions. Carbon dioxide is formed in the soil through many agencies, and the amount there present must often be very considerable. Generally speaking, it is always present in relatively much greater amounts than is to be expected from a consideration of its small partial pressure in the atmosphere above the soil.

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[1] Am. Journ. Sci., **8** (158), 245 (1899); **9**, 117 (1900).

[2] Bul. Soc. Min., **19**, 94 (1896).

It has been shown in the laboratory of this Division that solutions of carbonates in contact with ordinary atmospheric air always absorb some carbon dioxide, and for a given temperature and total concentration there is a definite, constant ratio between the amounts of carbonate and bicarbonate at equilibrium. Except possibly at very low temperature, or at very great dilutions, there is always a considerable amount of normal carbonates present. The equilibrium can be displaced toward the formation of more bicarbonates if the partial pressure of the carbon dioxide in the vapor above the solution be increased—that is, in effect, by dissolving more carbonic acid in the solution. But, as has been just said, these conditions obtain in the soil, since there is generally an excess of carbon dioxide in them. Mr. Briggs has recently shown that even dry soils show a remarkable power to absorb this agent from the atmosphere, and, together with the quantities being constantly formed in the soil, yield far more than enough to convert the carbonates to neutral bicarbonates and render the soil weakly acid. It is not to be supposed that this implies the necessary existence in the soil at any given time of considerable quantities of bicarbonates, for these substances are all fairly soluble and comparatively readily leached out, as witness the fact that the soils derived from the decomposition of limestones are nearly always deficient in lime. Great differences exist in this respect, however, as is brought out very clearly in contrasting the behavior of calcium bicarbonate and magnesium bicarbonate. The researches of Treadwell and Reuter[1] indicate that calcium hydrogen carbonate, or the bicarbonate, is a fairly stable compound, and can even exist as such in solution when the partial pressure of the carbon dioxide above the solution is quite low. Being also fairly soluble, the calcium in this form of combination is quite readily leached away. Magnesium hydrogen carbonate, on the other hand, is exceedingly unstable, and can only exist as such in the presence of large amounts of free carbon dioxide. In consequence it very readily inverts to the less soluble normal carbonate, and is less readily removed from soils by leaching. This subject is now being investigated experimentally in the laboratory of this Division.

The effect of dissolved carbon dioxide itself, or the resulting carbonic acid, has long been the subject of controversy and the evidence presented by various investigators is very conflicting. That a considerable amount of ionic hydrogen must be present in a solution saturated with respect to carbon dioxide would lead, according to investigations of Kahlenberg and True[1] and of Heald,[2] to the notion that such a solution must be toxic to plants. Kearney, in the laboratory of this Division, has shown that this is certainly not true in some cases. Further, the ground solutions must often contain very large amounts of carbon dioxide, even when plants are growing in a most satisfactory manner. The subject obviously requires more careful investigation.

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[1] Zeit. für Anorg. Chem., **17**, 170 (1898).

SUPPOSED POISONOUS ACTION OF HEAVY METALS.

It has long been noted that salts of the heavy metals in general have a strongly toxic effect on plants. Many investigations, for instance, have been made with the salts of iron and of copper, and it is generally believed that these metals have been definitely proved to be most harmful when dissolved, even in quite small amounts. While it can not be said that these conclusions are in themselves wrong, it would seem that they may in many cases be open to criticism, in view of the methods used in their investigation. It should be remembered that these metals are quite weak bases as compared with the acids to which they are united, and their salts on going into solution must and will be considerably hydrolized with the formation of some small amounts of free acid. The researches of Kahlenberg and of True[3] have shown that the toxic effect of the hydrogen ion is relatively very great indeed, a concentration of about one reacting weight of any strong acid per 6,400 liters of aqueous solution being sufficient to cause the death of plants. So that it is a question worth serious consideration as to whether or not the supposed toxic action of the metals was not in fact due to the hydrolized acid formed when the metallic salts were brought into the culture solutions.

SOIL ANALYSES.

To obtain a method of analysis which would give a true indication of the mineral constituents of the soil available for plant nurture has long been the subject of investigation. It was early recognized that the ultimate analysis of the soil would not furnish the data desired, for questions of solubility, etc., entered into the problem, and it was obvious that a distinction must be made between the *available* plant food and the total amount of the constituents which go to make up the food which might be present in the soil. Various solvents have been tried and the attempt made to correlate the amounts thus extracted from the soil with that taken from the soil by various crops. Not only have various acids been tried, but solutions of various concentrations. The difficulties presented have been found to be very great, for it is obvious that the nature of the action of strong mineral acids must be quite different from the weak acids normally present in the soil during plant growth. This has led in recent years to two notable series of investigations. Dyer has attempted to prepare a solution which would more closely simulate the acid solution about the roots or root hairs of plants. It is obvious that the acids excreted by root systems will not come in contact with all the particles of the soil, but only with the contiguous ones, at least in its first concentration; that the acidity of these secretions from different plants in different degrees of maturity or of different species might well be expected to differ widely; that the time factor must enter very largely on account of the slow rate of solution of these slightly soluble soil components. It has been claimed for his method that the amount of the principal mineral foods extracted, i. e., potash, lime, phosphoric acid, bears a strikingly constant relation to the well known cropping value of lands, certainly for the Rothamstead soils. Whether or not it will hold for other soils is open to doubt, evidence pro and con having been brought forward. But as a matter of fact, it does not appear that any material advantage has been shown by this method, for exactly the same claim has been made for hydrochloric acid extractions—that the amount of plant food dissolved is a *factor* of that available.

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[1] Kahlenberg and True, Bot. Gaz., **22**, 81 (1896); Kahlenberg and Austin, Jour. Phys. Chem., **4**, 553 (1900), True, Am. Jour. Sci. (4) **9**, 187 (1900).

[2] Bot. Gaz., **22**, 136 (1896);

[3] Loc. cit.

Maxwell, in a series of ingenious papers, has proposed a method involving the digestion of soils with dilute solutions of aspartic acid. His reasoning is quite different in some respects from Dyer's, but in the main the two methods are closely analogous. While it may be admitted that the aspartic acid solution does extract plant food from the Hawaiian soils in proportions comparable to the amounts truly available, it does not follow that it will answer as well for other soils; and, moreover, the objection still holds that no advantage over the hydrochloric acid digestion is really gained by its use for what it is claimed to show is a probable factor of the available plant food.[1]

The question then becomes pertinent why any solvent would not do as well, for instance, sodium chloride. The answer is that the advantage in using an acid is mainly an analytical one; the excess of acid, mineral or organic, can be gotten rid of readily, leaving no awkward residue to interfere with the determinations of the materials extracted from the soil. Moreover, from the point of view of the electrolytic dissociation hypothesis acids present a decided advantage, in that one of the ions resulting is hydrogen, not a common ion with any furnished by the mineral electrolytes in the soil. Therefore the solvent action of acids might be expected to be much greater than that of the corresponding salts, which fact is borne out by experience. The strong mineral acids would of course have the greater solvent action in comparison with the weak organic acids.

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[1] Dr. Wiley informs me that the results of an extended investigation in his laboratory indicate that an analysis of the material extracted from a soil by digestion with a hundredth normal solution of hydrochloric acid gives a much closer approximation to the effect of a growing crop than any scheme yet proposed. The results of this investigation will shortly be published.

From the facts just presented it would seem that the various other methods do not present any real advantages over digestion with hydrochloric acid, while digestion with the latter reagent presents distinct analytical advantages. It does not seem worth while to displace it, therefore, until another method which does present distinct advantages has been proposed. That such a method may be devised is earnestly to be hoped, but it must come from a consideration of all the factors involved in the problem and can scarcely be expected to result from purely empirical work. A thorough study of these factors must necessarily be a precedent for intelligent attempts along this line.

ABSORPTION BY SOILS.

Another peculiarity of soils must be considered. It has been well established that solutions, when passed through mixtures of finely divided material, undergo radical changes. The filtering out of colored materials not mechanically held but actually dissolved, by means of charcoal or "bone black," is a familiar case. The great difficulty experienced by all analysts in washing certain soluble salts from precipitates or filter paper is another illustration of this property. It has been clearly shown that in general any solid surface in contact with a solution causes a tendency to manifest itself in the dissolved substances to concentrate in a very thin layer of the solution next the solid surfaces. That this effect is very limited is evident; otherwise our solutions in vessels of ordinary size would not approximate the condition of perfectly homogeneous mixtures. That it might be of immense importance, however, in capillary spaces is very probable. What the effect of the nature of the surface of the solid in contact with the solution may be has received but scant attention so far, other than in the case of the growth of crystals in contact with their own solutions, or as to the area of surface exposed. But the nature of the substances dissolved, and especially when the substance is an electrolyte, is known to be a most important factor. That some salts can be readily washed through a soil, while others will remain in the most persistent way, is well known. That a considerable difference exists in the way in which various salts will be brought to the surface by capillary movements of the soil solution has been established. Thus the soils may be said to show a selective absorption or ad-sorption, as the phenomenon is now generally known. It must be candidly confessed that this phenomenon is not at all well understood. Comparatively little study has been given to it in the past. It is now the subject of investigation by Mr. Briggs in the laboratory of this Division, and much interesting information and data in this connection will soon be available. Another way in which the soil shows a selective absorption must be noted. It was early observed by Liebig, Way, and other investigators that if a solution of an ammonium salt be passed through a soil the ammonium radical was very largely retained by the soil. In the case of ammonium chloride, for example, a weak base is combined with a very strong acid and some hydrolysis is to be expected. The question might at once be asked, Why does the ammonium hydrate remain behind and let the acid residue be washed out when the ammonium hydrate is as soluble or more soluble than the acid? It might in turn be answered that the soil does, in fact, show a decided selective absorption toward ammonium hydrate, as shown by the experience of Liebig and Way when passing solutions of ammonia through soils. This may be due in part to a replacement of other bases by ammonium in the silicates of the soil, the stronger bases being taken out by the stronger acids or by other possible chemical reactions, of which several readily suggest themselves. It is well to bear in mind that the alkali bases and ammonia solutions, although the substances are very soluble, do show a marked tendency to remain on solid surfaces. The difficulty with which they are washed from the hand, for example, is very striking, and it would seem that it is probably due to a saponifying action on the grease. That organic matter of this general description is present to some extent on soil grains and may hold back in part the hydrolized ammonia seems not improbable. It is hoped that some experimental data bearing on this view will be available soon.

Quite recently an investigation by Œchsner de Conick[1] has been published, of which some of the experimental results are interesting in this connection. It would seem that when solutions of salts of some of the heavy metals are passed through animal charcoal a selective absorbtion is apparent. For example, in the case of a solution of ferric chloride practically all the iron was retained in the charcoal, the acid going through. This salt, it should be observed, is one which hydrolizes very readily, yielding the very slightly soluble ferric hydrate as one product. It is quite conceivable that on coming in contact with the large surface afforded by the animal charcoal, either through adsorbtion or otherwise, concentration changes take place in the solution, followed by hydrolysis, the precipitation of the insoluble iron hydrate, and the ready leaching of the very soluble hydrochloric acid. Similar phenomena, differing only in degree, might be expected in the case of soils being the filtering media. Further study along these lines would undoubtedly yield results of great practical importance as well as of scientific interest.

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[1] Compt. rend., **130**, 1627 (1900).

RÔLE OF ORGANIC MATTER.

The organic matter of the soil merits some attention here. It is a complicated subject, no doubt, and no attempt to treat it exhaustively is contemplated at this time. Whether it be the accumulations of many decaying vegetations from the growth of successive years, as in the case of virgin soils, or whether it be formed partly from decaying vegetation and partly from the addition of organic manures, this material contains plant food originally taken from the soil and in the process of decay returned to its original source.

Besides returning the mineral constituents to the soil, and in general in a form readily assimilable by crops, the ultimate decay of the organic matter would be expected to yield carbon dioxide, water, and nitric acid. These substances are undoubtedly found, but as the result of direct oxidation, of microorganisms, enzymes, etc., many intermediary substances are formed. In many cases they are not at all well understood. It seems to be accepted by many that the principal products thus produced are acids or amido acids of the aliphatic series. These substances, while generally subject to further decomposition through the action of microorganisms, ferments, etc., nevertheless play their part in the soil meanwhile as weak electrolytes, as has been pointed out in discussing the acid reaction common to most soils.

SUMMARY.

It is believed that the views presented above, while themselves speculative in some respects, together with the facts brought out, justify the following general conclusions:

(1) The mineral, and to a large extent the organic, components of the soil are electrolytes, and soil solutions are mainly solutions of electrolytes.

(2) The hypotheses of electrolytic dissociation and hydrolysis in aqueous solution give rational explanations for many phenomena hitherto regarded as inexplicable or exceedingly obscure.

(3) The rational procedure in the chemical investigation of the soil, from the point of view of its relation to crop culture, is to study the soil solution and in what manner it is modified by contact with the solid and gaseous components of the soil.

CLASSIFICATION OF ALKALI SOILS.

FORMATION OF ALKALI.

In order to obtain an intelligent appreciation of the practical problems presented by the accumulation of alkali in the soil, a clear idea as to its formation and accumulation is necessary. By "alkali" is meant any accumulation of water-soluble inorganic material sufficient in

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amount to have a deterrent effect on vegetation. This amount varies quite widely, however, depending as to its lower limits among other things upon the nature of the plants which go to make up the vegetation. Such accumulations are characteristic of arid regions, owing to the fact that there is not sufficient rainfall to leach from the soils the more soluble materials resulting from the decay and weathering of the rocks and more complex soil components. This process is sufficiently well known and understood to render further explanation at this time unnecessary. It is not generally recognized that true alkali conditions may and occasionally do occur in humid regions and are in their general features strictly analogous to those of the arid regions. Some details as to this point will be given later.

It is not proposed to discuss here why or how alkali comes to be present in a soil or soil crust, but it will be desirable to describe certain general changes, physical and chemical, which it undergoes after accumulating in any given area. These changes are brought about mainly through the agency of water.

In general all the components which go to make up the alkali in any particular case are present in the soil in some form or other before the application of water, although sometimes salts which materially affect the character of the alkali of an area may actually be brought in by irrigating waters.

The various salts composing the alkali vary greatly in solubility. The more soluble salts will naturally go into solution more readily and rapidly than the less soluble ones. It will be convenient to consider the various phases of alkali presented to our attention as the results of the action of aqueous solutions of certain soluble salts upon less soluble salts. In general the substances which form the alkali of arid regions consist of either chlorides, sulphates or carbonates of sodium, potassium, calcium, and magnesium, or mixtures of two or more of these salts. Other components occasionally enter, as nitrates, phosphates, or salts of barium, strontium, etc., but these may safely be considered as unusual or at least as relatively unimportant.

Alkali has been conveniently classified as white and black. The white alkali, although in appearance it may not be and frequently is not white in color, is that form in which no sodium nor potassium carbonates appear as ingredients; the black alkali is that form in which sodium carbonate is an essential ingredient and by its solvent action on organic matter often gives a dark color to the mass, although very frequently it is found in quite a white condition. This classification has been a very useful one in the past and is yet in some ways a convenient one, although it is often very unsatisfactory. For many purposes a classification based more specifically upon the chemical characteristics of the alkali or system of salts present would be preferable. That such classification can readily be made it is hoped will become evident as this paper proceeds. It may be said at once that while the data and analyses of other investigators have been considered and weighed, the material accumulated in the studies of this Division has naturally had a paramount influence in forming the views here expressed.

METHODS OF ANALYSIS.

While the methods now in use in the investigations of the Division of Soils present many unique features, none of them seem to call for special comment at this point except the chemical analyses. These need a few words of explanation, as they present certain radically different features from the analyses obtained by the methods of other investigators. In consequence, no fair comparison of the results from different sources can be made without at least allowing for the differences in the methods employed. This subject has already been commented upon in a former paper from this Division,[1] and a detailed description of the methods adopted in this Division will shortly be given in another publication.

It may be frankly admitted that it has not as yet been possible to devise any scheme which will give positive and direct knowledge as to the composition of the ground solutions as they actually exist in the soil; nor does there appear to be any prospect of the early realization of this important and much desired object. The relations of the various solutes or substances in solution are largely dependent upon the absolute concentration of the solution, absorptive power of the soil grains, and other factors about which we as yet know very little indeed. It has been necessary, therefore, to adopt an arbitrary method.

It is the practice in this laboratory to stir 50 grams of the soil or crust into a liter of distilled water and then allow the suspended material to settle for twenty-four hours. Five hundred cubic centimeters or more of the supernatant liquid is then decanted through a folded filter and the various determinations made upon 100 cubic centimeter portions of the filtered solution, which are taken to represent the soluble portions of a 5-gram sample of the original soil or crust. Of course in some cases the concentration of solution thus obtained is not the most favorable for the analytical work to be done, in which case it is modified accordingly either by taking a larger sample and concentrating the filtered solution or by diluting to a convenient amount a definite portion of the filtered solution; but for the sake of uniformity all leachings of the original soil or crust samples are made in the proportion of 1 gram of sample to 20 cubic centimeters of water. The only other feature worthy of comment is the method used for determining the amounts of carbonates, bicarbonates, and chlorides present. These three components are determined in one aliquot portion of the solution, according to the method described in former publications of this Division.

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[1] Report No. 64, United States Department of Agriculture, 1900.

It is of course obvious that the relative proportions of carbonates and bicarbonates thus found in the soil leachings are not those which will exist in the soil itself. The distilled water used in the laboratory is often very rich in dissolved carbon dioxide, and the amount so dissolved is a varying quantity. It will disturb the distribution of the bases between the carbonic ($-CO_3$) acid and hydrogen carbonic or bicarbonic ($-HCO_3$) acid. This distribution is dependent upon the absolute concentration and temperature. Still other factors enter, as the partial pressure of the carbon dioxide in the atmosphere above the solution. This factor is unquestionably much modified in transit from the field to the laboratory. It does not seem advisable to simply state both carbonates and bicarbonates as carbonates alone, because totally misleading conclusions are often indicated by this procedure. It is our practice, therefore, to state the bicarbonates as well as the carbonates as actually determined, and, when the ratio of these components is desired, to supplement the laboratory determination by one made in the field at the time the sample is collected. In the case of water sent in for examination the amounts of carbonates and bicarbonates found are always stated as such, but only in exceptional cases is the dissolved but uncombined carbon dioxide determined.

The actual determination of the carbonic acid and hydrogen carbonic acid as such in all solutions examined serves another useful purpose in that by determining all the acid and basic radicals which may be present in the solution, and then balancing them as salts, it is possible to check the accuracy of the analytical work. This is a matter of great importance when, as is frequently the case, a large number of analyses must be made in a limited time, and the making of duplicates for each analysis is quite out of the question under the exigencies of the work.

The statement of the analytical results is now made in terms of the possible ions which may be formed in the solution. For the present it is proposed to continue the statement in the form of combinations as salts, as a concession to those workers who have not become accustomed to the more rational form; but it can not be insisted too strongly that this method is inherently wrong and may be misleading. The particular way in which the data are combined is, in the vast majority of cases, a purely arbitrary matter. It is perfectly certain that the salts as thus stated never exist in the solution in the amounts indicated. In fact, there is every reason to believe that all the possible combinations which the various ions can form are present to some extent. It would, therefore, seem much better and safer to abandon this arbitrary method of stating and considering analyses, except under special conditions, and to become accustomed to the consideration of the possible ions which might be formed.

PECOS TYPE.

From a general inspection of the analyses of the water-soluble constituents of the soils and crusts of the alkali areas, together with a study of the conditions in the field, it would appear that the nature of the alkali in any particular area has predominating features which may be considered as characterizing and differentiating it from other alkalies. In the Pecos Valley it has been made very evident that the predominating feature is the contact of waters carrying considerable quantities of sodium chloride, with the gypsum found abundantly in the soil, the gypsum, in fact, being in some places the main component of the soil. As has been pointed out above, the sodium chloride was also in the soil in the solid phase before the advent of the water, which may, in its initial condition, when applied to the land, have been quite pure. On the other hand, the water frequently does carry much matter (mainly sodium chloride) in solution long before it reaches the area under consideration. The sodium chloride, being so much more soluble, will be taken up long before the gypsum is appreciably affected, and we are therefore justified in regarding this problem as the action of water solutions of sodium chloride upon gypsum ($CaSO_4 . 2H_2O$) or the dihydrate of calcium sulphate.

In aqueous solutions a reaction takes place between gypsum and sodium chloride which may be represented thus:

$$CaSO_4 + NaCl \rightleftarrows Na_2SO_4 + CaCl_2$$

part of the calcium and sulphions of the sparingly soluble calcium sulphate being converted into calcium chloride and sodium sulphate, compounds much more soluble than gypsum. If the solution were saturated with respect to gypsum, by being kept in contact with this substance, more of the gypsum in the solid phase would go into solution to restore the equilibrium between the solid gypsum and its solution, which had been disturbed by the withdrawal of some of its component parts or ions to form sodium sulphate and calcium chloride. In other words, the gypsum becomes more soluble on account of the presence of sodium chloride and the solution more concentrated with respect to the total salts dissolved.

By the movement of the solution through the capillary spaces of the soil and the evaporation of the water at the surface the salts are brought toward the surface of the soil. If the solution becomes saturated before it reaches the surface, separation of solid salts will take place, but in any case the tendency will be toward the formation of a crust of the dissolved salts on the surface of the soil as they separate from solution on the evaporation of the water. The various salts on separating are more or less well crystallized, with the exception of the calcium chloride, which, on account of its great hydroscopiscity, is dehydrated only under extreme conditions and probably never separates in well-defined crystals in the field. It is evident that if water be added to the crust the rate at which the several components will redissolve is dependent not only on their respective solubilities but also very largely on their physical states, whether in large, well-defined crystals, exposing a relatively small surface to the solvent action of the water, or in a fine, pulverulent condition, thus exposing a very large surface to the action of the solution, etc. The calcium chloride would evidently go into solution more quickly than any other component of the crust. If the water were allowed to stand in contact with the crust for a sufficient length of time all the salts would dissolve, to a greater or less extent, until a state of equilibrium was reached; but this is not what takes place when water is added, either by irrigation or by rain. It has been pointed out by Mr. Thomas H. Means that the downward movement of such waters in the soil is quite rapid and is through the larger soil spaces, in contradistinction to the slow, upward movement of these waters through the capillary soil spaces; consequently on the addition of water to the soil or crust the calcium chloride, which goes into solution so much more rapidly than the other salts, is rapidly leached out and carried far down into the lower depths of the soil. When evaporation again sets in at the surface the calcium chloride, which has been carried so far below the other salts, either fails to reach the surface altogether or does so in lessened amounts. Thus it is that we practically never find calcium chloride and sodium sulphate in the crust in equivalent amounts, as we should expect *a priori* on the basis of the reaction between sodium chloride and calcium sulphate with the formation of some calcium chloride and an equivalent amount of sodium sulphates.

So far in this discussion it has been tacitly assumed that the rate of movement of the different salts in the capillary spaces of the soil, *after they have gone into solution*, is the same for all salts. Some investigations by Mr. Briggs indicate that this assumption is probably correct, in spite of the long-held opinion that marked differences exist; but even if there be different rates for the different salts, it is incredible that the differences could be of such magnitude as to affect materially those features of the phenomena which have just been considered.

The calcium chloride which has been washed down into the subsoil accumulates there in certain places, and then on prolonged drought is sometimes brought to the surface in very large amounts in spots of limited area. On account of its well-known and very great property of deliquescence it keeps the surface where it has accumulated quite damp, even during periods of protracted drought. This gives a darker appearance to the soil where the calcium chloride has accumulated than that of the surrounding drier areas where this salt has not accumulated, these darkened areas being locally known in the Pecos Valley as black alkali spots, although chemical examination shows them to be quite free from soluble carbonates.

The metathesis or interaction of calcium sulphate and sodium chloride is the predominating feature of the alkali in the Pecos Valley. It is modified to some extent by the presence of other salts, as the salts of magnesium, for example; but these latter are always present in much smaller quantities than are the calcium and sodium salts. Soluble carbonates are almost entirely absent and merit no attention in this area. Since the Pecos area was the first of the gypsum-sodium chloride type to receive extended investigation by this Division, it has seemed appropriate to give its name to this type of alkali. It is therefore proposed, tentatively at least, to classify areas in which the interaction of gypsum and sodium chloride is the predominating feature under the heading, Pecos type.

FRESNO TYPE.

It has become evident that in the area about Fresno the prevailing feature of the alkali problem from the chemical point of view is the contact of aqueous solutions of sodium chloride with calcium carbonate. Large quantities of calcium carbonate are found in the soils of this area. Frequently it is the cementing material for more or less extensive beds of hardpan at various depths, usually a few feet below the surface and generally parallel to it. The sodium chloride in solution on being brought into contact with calcium carbonate reacts at once as thus indicated:

$$CaCO_3+NaCl \rightleftarrows Na_2CO_3+CaCl_2$$

calcium chloride being formed, as in the Pecos type, but sodium carbonate being the other constituent instead of sodium sulphate as in the area last considered. The same general considerations apply here. The salts are brought to the surface by evaporation of the solvent and the movement of the solution through the capillary spaces of the soil. They are then, on the addition of water at the surface, partially dissolved and carried quickly down, the calcium chloride being more rapidly removed than the other salts during the process.

The study of this type presents some specially interesting phenomena. As has been pointed out elsewhere, the action between the calcium carbonate and the sodium chloride is much facilitated by the presence of carbon dioxide, this substance reacting with the calcium carbonate to form the much more soluble bicarbonate or hydrogen carbonate and this latter substance then reacting with the sodium chloride. The reaction then would be expressed thus:

$$Ca(HCO_3)_2+NaCl \rightleftarrows CaCl_2+NaHCO_3.$$

The sodium hydrogen carbonate thus formed would be brought to the surface and in much greater amounts than if the normal calcium carbonate had been its origin. On desiccation, the sodium hydrogen carbonate would be very largely inverted to the normal carbonate. Probably in the field the effect of carbonic acid just described is always considerable, for Mr. Briggs has shown that soil grains have the power of condensing very considerable quantities of carbon dioxide, the soil thus containing much more of this agent than one would suppose from its very small partial pressure in the atmosphere above the soil. Moreover, wet or dry areas containing much organic matter are, from the nature of the case, especially adapted to the formation and retention of carbon dioxide. In such areas the production of black alkali is notoriously great. It is very probable, as has been pointed out in another place, that practically only calcium hydrogen carbonate or the bicarbonate is to be considered in soil solutions in contact with solid calcium carbonate.

The presence of magnesium carbonate with the calcium carbonate, as is frequently the case in soils of this class, introduces some modifications as to degree in the formation of soluble carbonate; for magnesium carbonate is more soluble than calcium carbonate, and therefore its active mass would be greater. Magnesium hydrogen carbonate is less stable than the corresponding calcium salt, but more soluble; and magnesium readily forms basic carbonates in concentrated solution, which are very alkaline. Therefore the contact of this substance with sodium chloride would be expected to yield soluble carbonates more readily and in much greater amount than would the calcium carbonate alone. These views are fully substantiated by the investigation of certain alkali soils from California containing much lime-magnesium carbonate.

The occurrence of calcium chloride spots is quite common in this area. Usually there is also a small amount of soluble carbonates or bicarbonates present. When the calcium chloride is large in amount, the amount of soluble carbonate is quite small, and not infrequently disappears altogether; for calcium carbonate, being quite insoluble as compared with the other salts present, and likewise being but little dissociated, would be formed and precipitated as such. In such spots the application of water to the surface will first wash the excessive amount of calcium chloride away, and then the calcium carbonate will in turn react with the sodium chloride to re-form sodium carbonate. The formation of small amounts of black alkali may well be expected as one of the first results of irrigating such spots. With good drainage, however, the evil would be but a temporary one.

In areas of this type are occasionally found small deposits of nitrates. This is to be expected, for here the nitrifying organism finds lime carbonate to neutralize the excess of nitric acid formed, and its functions are thus not interfered with and kept down to a low limit by an accumulation of its own product.

Since Fresno is the first area in which these relations have been carefully studied and in which they are not disguised to any considerable extent by the presence of other salts, it is proposed to designate alkali areas of the calcium carbonate-sodium chloride class as belonging to the Fresno type.

SALT LAKE TYPE.

The type of alkali most commonly met is one in which the conditions observed may be regarded as the result of the action of aqueous solutions of sodium chloride upon calcium carbonate (or calcium hydrogen carbonate) and gypsum simultaneously. By the action of the sodium chloride upon the calcium carbonate some sodium carbonate would be formed, and also an equivalent amount of calcium chloride. By the action of the sodium chloride upon the gypsum sodium sulphate would be formed, and again an equivalent amount of calcium chloride. This second reaction would take place in the direction of the formation of calcium chloride to a greater extent than the first, for the sulphates are stronger electrolytes than the carbonates, and, moreover, the solubility of the gypsum is probably in most cases greater than the solubility of the lime carbonate, even though there be much carbon dioxide present. The formation of the common product, calcium chloride, would tend to retard both reactions in the direction of the formation of this substance, but more the one involving the calcium carbonate. The formation of the corresponding sodium carbonate is therefore very much lessened by the presence of the gypsum, a fact which has long been known empirically and which has been sometimes employed in the amelioration of the conditions in land containing black alkali by the addition of gypsum or land plaster. The reaction between the gypsum and the calcium carbonate would simply result in lowering the solubility of both salts, because they yield a common ion, but the effect would be much more marked in the case of the carbonate, both on account of its being a weak electrolyte and of its lesser solubility. Therefore the amount of the lime carbonate in the solution, or its "active mass," is much lessened with a corresponding lessening of the extent to which it can react with the sodium chloride to form sodium carbonate.

It must be remembered that the rôle of carbon dioxide is probably of great importance in this connection. The amount of this substance in the soil atmosphere may be quite large, and in consequence the solubility of the lime carbonate may be considerably increased by the formation of the hydrogen carbonate. This might well increase somewhat the amount of sodium carbonate formed and at the same time lessen to some slight extent the formation of sodium sulphate. This is a matter of great importance, for it indicates that in this mixed type of alkali some soluble carbonates are to be expected, although the amount will be small and may usually be neglected in an economic consideration of the area involved; but in the case of the application of gypsum for the correction of black alkali, the relative proportion of gypsum applied, to the salts already present is small. It may be expected to fulfill its rôle temporarily by acting on the soluble carbonates in immediate contact with it; but an increase of the soluble carbonates, by more of this material coming to the surface from lower depths or by its formation from an increased solubility of the lime corbonate through an increase in the carbon dioxide dissolved in the ground solutions, will require further additions of land plaster. Therefore this method of ameliorating black alkali can be regarded as but a temporary expedient, and has the further disadvantage that the action of the sodium chloride upon the gypsum results in an increase of the soluble salts in the soil. On the other hand, the presence of a large proportion of soluble lime salts has the apparent effect of enabling plants to withstand much larger quantities of other salts than would be possible in the absence of calcium from the soil solutions.

The characteristics of this type of alkali are, then, the presence of soluble chlorides, sulphates, and the relatively small but varying amounts of soluble carbonates.[1] The first area containing this type of alkali that received detailed attention from this Division was in the Salt Lake Valley, Utah. The type is therefore tentatively designated as Salt Lake type.

MODIFIED TYPES.

At Tempe, Ariz., it appears that the original conditions are very similar to those at Fresno, Cal., in that the principal reaction involved is the one between sodium chloride and calcium carbonate. But the investigations of Professor Forbes, of the Arizona Experiment Station, and of Mr. Means, of this Division, have shown that considerable amounts of soluble sulphates are constantly being added to the soils through the application of irrigating waters carrying rather large amounts of these substances in solution. The result is to gradually modify the original type of alkali, making it more nearly resemble the Salt Lake type, although the amount of lime sulphate formed in the soil is hardly sufficient to justify a reclassification under this latter heading. The area is rather to be regarded for the present as a modification of the Fresno type.

In the virgin soils of this area, or in those very recently brought under irrigation, the formation of soluble carbonates has frequently been noticed; but in those soils which have been irrigated for some time with the sulphate-carrying waters the occurrence of soluble carbonates in more than traces, or practically negligible amounts, has been found to be unusual. These observations are entirely in accord with the ideas developed above.

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[1] See analyses, p. 111, Report 64, Field Operations of the Division of Soils, 1899, U. S. Department of Agriculture.

In the valley of the Sevier River, Utah, the alkali areas are of unusual interest, the alkali being essentially of the Fresno type. The soils are uniformly underlaid by sandy formations, giving good natural underdrainage, and hardpan areas are, therefore, unusual. Even in the virgin soils the amounts of alkali are never very large, and in the irrigated areas, as might be expected with good underdrainage, the amounts of alkali are considerably diminished.

It has been found by Mr. Gardner, of this Division, that in the virgin soils of this area there are considerable amounts of soluble normal carbonates, but as the total amounts of soluble salts decrease in the soils the carbonates decrease also, the proportion of hydrogen carbonates to normal carbonates greatly increasing. This is in entire accord with the laboratory observations of Cameron and Briggs[1] on the equilibrium between carbonates and bicarbonates in aqueous solution. A direct comparison between the field observations and those of the laboratory is not always possible, for the conditions in the laboratory study involved contact of the solution with ordinary atmospheric air, containing a very small amount of carbon dioxide, while the soil solutions in many cases must have been in contact with an atmosphere containing many times the amount of carbon dioxide to be found in ordinary air. In a general way, however, the agreement between the two sets of observations is very satisfactory. It was found that seepage waters fresh from these soils contained, as a rule, no normal carbonates, although always containing some hydrogen carbonates. If these waters be allowed to stand in contact with air for a while, either in pools or by running in the river courses or canals, so that they more nearly approach equilibrium with the air, there is always a partial inversion of the hydrogen carbonate to normal carbonates, as evidenced by the reaction of the solutions toward phenolphthalein.

These observations have an important bearing on alkali studies, as they show most clearly that not only is underdrainage of great importance in diminishing the actual amount of alkali in the soil, but that where there is black alkali this much dreaded substance is at the same time very largely changed to the much less noxious hydrogen carbonate. The change becomes the more nearly complete as the total amount of soluble material decreases.

BILLINGS TYPE.

In the valley of the Yellowstone, in Montana, a distinctly different type of alkali is found.[2] There the alkali consists almost entirely of sulphates, only traces of chlorides being found. While soluble carbonates occur, as has been amply demonstrated in the laboratory of this Division by examinations of crusts collected near Billings, they are always in very small amounts, which can practically be disregarded in a consideration of the problems presented by this area. Crystals of gypsum are abundant in the Yellowstone soils and in the rocks from which these soils are formed. Occasionally the gypsum is associated with relatively small calcium carbonate deposits. Sodium or magnesium sulphate, the most common of the soluble salts of this area, would decrease the solubility of gypsum because they furnish a common ion in the SO_4 group. They would react to some extent with calcium carbonate, making it more soluble, according to the following scheme:

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[1] A description of this work will appear at an early date in another publication of this Division.

[2] The Alkali Soils of the Yellowstone Valley. By Milton Whitney and Thomas H. Means, Bul. 14, Division of Soils, U. S. Department of Agriculture, 1898.

$$Na_2SO_4+CaCO_3 \rightleftarrows Na_2CO_3+CaSO_4.$$

From the well-known properties of the individual salts, it could be prophesied, what is actually found to be the case, that equilibrium in this system is reached when the reaction is mainly from right to left. In other words, the solubility of calcium carbonate is but slightly increased in the presence of sodium sulphate. In the presence of carbon dioxide, and the consequent formation of calcium bicarbonate or hydrogen carbonate, the reaction is much further displaced to the right, as indicated by the above scheme. On desiccation at the surface the sodium hydrogen carbonate would mainly invert to the form of the normal carbonate, and in the presence of so much gypsum and magnesium sulphate as is always present in these soils it would be quite rapidly converted to the slightly soluble alkaline earth carbonates and sodium sulphate.

Practically the only salt to be considered in this area is sodium sulphate and possibly in some cases magnesium sulphate. It would appear that the Pierre shales, from which a large portion of the soils of this valley are derived, contain considerable quantities of sulphide of iron as marcasite or pyrites. On weathering this material is superficially oxidized to the very soluble ferrous sulphate. By further oxidation and hydrolysis the major part of the iron is precipitated as the very slightly soluble ferric hydrate, this substance then becoming more or less mixed with carbonate of iron by absorption of carbon dioxide.

Hydrated carbonate of iron has been identified in some of the samples from this locality now in the collection of the Division. At the same time that the ferric hydrate was precipitated free sulphuric acid must have been formed. This acid was quickly neutralized by its action upon the other mineral components of the soil, especially lime carbonate. It would seem probable that this process is in large part responsible for the sulphates so abundant here.

LIMITATIONS OF THE CLASSIFICATION.

The classification here proposed seems expedient at the present stage of the studies of this Division upon alkali problems. It is desirable to have a nomenclature which will go further than the division of alkali into black and white, respectively, and which will include as much as possible of those ideas now held to be involved in the processes taking place in the material systems (solutions) which have been considered above. Whether or not the form it is given here will prove well advised time and usage will determine. Some, at least, of its shortcomings are obvious enough now. Other types than those described above may have to be added, and this in itself may ultimately prove a very weak point, although for the present the classification be justified. The basis of the classification is professedly a chemical one alone. Other considerations, such as the physical or mechanical composition, texture of the soil, etc., may and probably will at some time have to be incorporated and an entirely different set of types then selected. At the present stage of our studies, however, this does not seem to be essential or even desirable. It is believed that the formulation of our ideas in the description of the types here given will lend light to the handling of the problems involved and the classification itself will be found useful and sufficient for some time to come. That modifications must come with further work is one of the most interesting and cheerful features to investigators in this line, for it is a most positive indication that there is much yet to be learned and that the ground is clearing for further progress in this most important field.

SUMMARY.

The views presented in this paper may be summarized as follows:

(1) A classification as black alkali or white alkali, depending upon the presence or absence of sodium carbonate, is inadequate in view of our present knowledge of alkali phenomena. A more comprehensive classification is desirable. Such a classification appears to be possible on chemical grounds, considering alkali conditions as the result of the action of aqueous solutions of certain soluble salts upon less soluble salts.

(2) The action of sodium chloride solutions upon gypsum is the predominating feature in certain areas and seems to be well typified by the conditions in the valley of the Pecos in New Mexico. The solubility of the gypsum is apparently much increased by the presence of the sodium chloride due to the formation of the soluble salts, sodium sulphate and calcium chloride. In such an area practically the only salts which will have to be considered in the ground solutions are sodium chloride and sodium sulphate as well as calcium sulphate. Calcium chloride is sometimes found concentrated to a considerable extent, but usually in localized and generally small spots. Owing to its keeping

the soils of these spots moister and, therefore, darker than the surrounding soils, such spots are locally known as black alkali spots.

(3) The action of solutions of sodium chloride upon calcium carbonate is the predominating feature of some areas. The region about Fresno, Cal., seems to furnish a good illustration of this class. As a result there is always found a greater or less formation of sodium carbonate, the soluble and very noxious component of black alkali, and the very soluble calcium chloride. Such regions are generally further characterized by the presence of a hardpan at a distance of a few feet below the surface and generally parallel to it, the cementing material of which is calcium carbonate. In such areas there is a tendency toward an accumulation of the soluble carbonates at the surface of the soil. Calcium chloride accumulations, in spots of comparatively restricted area, are frequent accompaniments and are often mistaken for bad black alkali spots, although the presence of soluble carbonates in more than very small quantities is an impossibility.

(4) The class of alkali most commonly encountered is that in which the predominating feature is the simultaneous action of solutions of sodium chloride upon gypsum and calcium carbonate. In such an area the formation of soluble carbonates can take place to only a very limited, generally negligible, extent. The apparent increase in the solubility of the gypsum is also much less than when the calcium carbonate is not present. The alkali of the Salt Lake Valley appears to be a good illustration of this type.

(5) Much less frequently other types of alkali are encountered, as at Billings, Mont., where the soluble material in the soils appears to be almost entirely sulphates.

(6) Modifications of the types described above are more or less frequently found. They may possibly be of such importance as to warrant a separate classification, as, for example, the conditions found to exist in the valley of the Sevier, Utah.

(7) The classification here proposed is believed to be comprehensive and is founded on scientific principles. It is elastic and will readily admit of modifications. Principles other than those now recognized in it may be introduced without the accompaniment of radical changes. It can be made as specific as the advance of our knowledge from time to time will justify.

(8) In conclusion it must be reiterated that the specific classes outlined above are suggested tentatively and rather as illustrating the principles involved than as final definitions. It is proper that the delimitation of the various classes should be made by those who come in actual contact with the phenomena in their field studies. The purpose of this paper will be accomplished if it furnishes a starting point for the gradual development of a comprehensive, scientific, conventional classification of alkali conditions.

OCCASIONAL OCCURRENCE OF ALKALI IN HUMID REGIONS.

CASE IN MARYLAND.

Early in May, 1900, while on a visit to the Maryland Experiment Station at College Park, Md., Professor Whitney observed a dark stain or crust alongside the dirt roadway running through one of the fields of the station's grounds. A small sample was brought to the laboratory of this Division, and on examination gave such remarkable results as to make a more thorough examination seem desirable. On request, Prof. W. T. L. Taliaferro, of the Maryland Agricultural College, kindly collected a sample for us. It consisted of a dark brown-colored crust taken from the surface of the soil to a depth of one-eighth of an inch. It was carefully separated from the soil beneath with a sharp-cutting chisel. The sample was taken from various spots on the dirt road as it crossed the field and outside the wheel tracks. The road had been made by scraping with a road machine the soil from the neighboring fields and throwing it in the center, being subsequently shaped. The road material, therefore, might be expected to be the same as the soil of the contiguous field, but so far as we have been able to learn nothing like the crust we have examined has been observed on the surface of the field itself. That it should be sought for is obvious from the results we obtained, and it is hoped that systematic observations in this direction will be made in the near future.

Fifty grams of the air-dried material were stirred into a liter of water. The mixture was thoroughly agitated from time to time and then allowed to settle for twenty-four hours. The supernatant liquid was decanted through a filter, and analyses[1] of the water soluble constituents made on 100 cubic centimeter portions. The results follow:

Total solids soluble in water, 1.83 per cent, composed as thus indicated:

NO_3	Cl	SO_4	Ca	Mg	Na	K
69.00	4.82	1.31	15.66	3.40	3.40	2.41

Combined in the conventional manner the results give:

$CaSO_4$	$CaCl_2$	$Ca(NO_3)_2$	$Mg(NO_3)_2$	$NaNO_3$	KNO_3
1.86	7.55	51.20	20.68	12.47	6.24

It thus appears that this crust contains nearly 2 per cent of readily water-soluble salts, more than enough to characterize the soil as an "alkali" soil if it had been found in the arid regions. It would certainly prohibit the growth of any of our ordinary crops if it extended to any considerable depth in the soil and with this concentration. The origin of this material is not evident, for we are informed that these fields had not been fertilized, at least recently, and certainly with no such large amounts as these analyses would indicate. We have, then, as far as can be seen, no special conditions to account for this phenomenon, and it follows that "alkali" conditions can occur even in humid regions. The idea suggests itself that possibly this phenomenon may occur much more frequently than has been suspected hitherto, and that it would be well in the future to look for its occurrence in humid areas and closely observe the accompanying conditions as to weather, climate, soil, moisture, etc.

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[1] Made by Mr. Seidell, of this Division.

From the figures given it will be observed that about 50 per cent of the soluble material was calcium nitrate, and that about 90 per cent was in the form of nitrates. In this respect this crust differs from those usually found in arid areas of the United States. Nitrates are found occasionally by our field parties and of course they can and do occur in large deposits, as in the well-known Chilean deposits, but the usual salts with which we have to deal in the arid regions of this country are chlorides, sulphates, and carbonates. These facts, while indicating probably material differences in the origin of these readily soluble salts, are not so important at the present stage of our studies as that they can and will accumulate in the surface soil to the serious detriment of the plants, and that the phenomenon as observed here in the humid East is closely analogous to its appearance in the arid West. Therefore it should be sought for during periods of severe drought, even when these periods be of comparatively short duration.

The water solution was examined for phosphates, but if present they were in such small quantities as to make their determination impracticable. Mr. F. P. Veitch of this Division has found that with strong hydrochloric acid he was able to extract about 0.1 per cent phosphoric acid (expressed as P_2O_5) from this crust, while his researches on the type formation to which this soil belongs shows but 0.035 per cent P_2O_5 or about one-third as much as this crust contained. It would seem, therefore, that even the more moderately soluble constituents show a tendency to accumulate in the surface crust as well as the most soluble constituents of the soil waters. It will be noticed that the crust was found on ground which had been rolled down smoothly and compactly, presenting a surface from which evaporation would take place much more readily than from the surface of loose earth in the contiguous fields. It was this rapid evaporation from the surface, undoubtedly, which occasioned the accumulation of the soluble material there.

CASE IN FLORIDA.

In January, 1898, while working near Starke, Bradford County, Fla., Professor Whitney collected a specimen of a peculiar-looking crust which he observed along the edge of a path in a pine woods. An examination of this material was made by Mr. Thomas H. Means, of this Division. Twenty-five grams of the material was thoroughly shaken with 500 cubic centimeters of water.

The material which had been thoroughly air dried or dried in the oven was very differently wetted. The soil grains appeared to be covered with an oily or greasy substance. The solution which was obtained was very dark in color and decidedly acid. About 0.70 per cent of the soil was found to have dissolved, of which 0.51 per cent was organic matter, leaving about 0.19 per cent of the soluble mineral matter. It was shown that practically the only base present was sodium, bare traces only of calcium, potassium, and iron being found. The acid present in greatest amount was shown to be hydrochloric acid. Sulphuric acid was also found and, strange to say, a considerable amount of phosphoric acid. This crust was decidedly different in composition, at least from the Maryland crust described above. It was more like the crusts found in some arid regions, in that it contained such a relatively large amount of sodium chloride. The rather large amount of phosphoric acid present is certainly not characteristic of the alkali crusts of arid regions, but is occasionally observed. The chief distinctions between the crust under discussion and those of the arid regions are the very large amount of organic material present, unusual in arid regions except in the presence of much alkaline carbonates, and the fact that the Florida crust contained but the one base, sodium, while the crusts of the arid regions contain usually calcium, magnesium, and potassium salts, as well as those of sodium. In the case of this Florida crust it will be observed that, like the case of the Maryland crust, it was found on a compacted smooth surface, from which evaporation was much more rapid than from the surface of the surrounding soils.

REPORTED OCCURRENCES FROM VARIOUS LOCALITIES.

Mr. Clarence W. Dorsey reports having observed the accumulation of water-soluble material at the surface in spots in fields at Biers post-office, near Cumberland, Md. The accumulation is sufficient after a spell of dry weather to kill the vegetation and to attract cattle as to a salt lick.

Similar accumulation appearing on the surface after more or less prolonged dry spells has been reported from Mississippi and Louisiana. In these cases it was concluded at the time the phenomena was observed that the soluble material was mainly sodium chloride, but precise data are wanting. Near Durant, Holmes County, Miss., there are spots reported[1] to be from a quarter to a half acre in extent, on which nothing will grow. If a seed germinates, it dies soon after it is up. The presence of sodium chloride has been shown. The spots remain as bare as a floor.

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[1] Samples 3919 and 3920, Division of Soils, U. S. Department of Agriculture.

Another example,[1] a soil collected about 10 miles north of Houston, Tex., contained 0.37 per cent of sodium chloride in April, 1899. Other examples from this area might easily be quoted.

The presence of iron sulphides in the soil or subsoil frequently occasions the presence of soluble sulphates on the surface during "spells of dry weather." By surface oxidation the iron sulphide is converted to the soluble ferrous sulphate. This salt is readily hydrolized in part, forming free sulphuric acid, which in turn forms soluble sulphates by action on the soil components. The soluble sulphates are brought to the surface by the capillary movements of the soil waters, and in dry weather are frequently deposited as a coating or crust on the soil. An interesting case of this kind occurring near Washington has been described by Merrill.[2] Mr. Bonsteel has called attention to a similar occurrence on the shores of Lake Cayuga in New York. Many such instances could undoubtedly be found.

From the foregoing descriptions it is evident that the essential differences between conditions obtaining in the soils of humid and arid regions are rather those of degree than of kind; that the fundamental forces at work are in reality the same, and that the study of the phenomena presented in one area can and should be of the greatest value in interpreting those of another area.

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[1] Sample 4002, Division of Soils, U. S. Department of Agriculture.

[2] Proceedings National Museum, Vol. XVII, p. 87 (1894).

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U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS.
MILTON WHITNEY, Chief.

SOLUTION STUDIES OF SALTS OCCURRING IN ALKALI SOILS.

BY

FRANK K. CAMERON, LYMAN J. BRIGGS,
AND ATHERTON SEIDELL.

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1901.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., June 1, 1901.

SIR: I have the honor to transmit herewith a technical paper on Solution Studies of Salts Occuring in Alkali Soils, giving the results of certain investigations carried on in the laboratories of this Division which have an important economic bearing on the alkali problem of the arid lands of the West, and, in general, on the nature and composition of soils.

In accordance with the usual practice in such matters, this manuscript has been submitted to the Chief Chemist of the Department for approval of the chemical methods involved.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

PREFACE.

The investigations described in this Bulletin have been made within the past year (in the laboratories of soil chemistry and soil physics of the Division of Soils) for the purpose of elucidating problems or difficulties encountered by the field parties in their work, for which adequate published data were not available.

In many cases the investigations have been carried beyond the point necessary to answer the specific questions for which they were undertaken. This has seemed advisable, as unlooked for questions have arisen during the progress of the work, and a clear understanding of the problems could be obtained only by a more complete study. A just criticism would be that for the most complete scientific value the investigations should have been carried out more completely and in further detail. This has been clearly recognized, but the exigencies of the public service and the limited time available for this work have not permitted the more exhaustive examination of the subjects. The work here recorded is rather to be regarded as preliminary investigations to open the field for study. Moreover, these studies have been made essential integral parts of a systematic line of investigation on the properties of soil solutions which the Division has undertaken.

The importance of the general investigation has been dwelt upon at length in recent publications of this Division, and it will be necessary only to recall the fact that a comprehensive knowledge of the nature and functions of soil solutions is absolutely essential to a rational study of such practical problems as the relation of crops to soils, or to soil fertilizing, to illustrate the economic importance of any investigation which can throw light upon the subject.

This Bulletin is essentially a technical paper, and it is not the purpose to consider specific practical applications of the investigations described, although some of them are referred to for the purpose of illustration. It would seem that the practical application can best be considered in the reports of the field parties, when the problems themselves are under discussion, but some general applications of the work may with advantage be pointed out here.

The investigations described in this Bulletin are more especially concerned with problems presented by "alkali" lands in the arid regions of this country. There is a characteristic difference between the studies of soils in humid and arid regions. In the soil solutions of humid regions there are small amounts of constituents, derived from the slightly soluble soil components, which make the solution a culture medium for plant growth. These mineral plant nutrients, both as to their absolute amount and relative proportions, are of the first importance in the study of these soils. In the soils of arid regions these necessary plant nutrients are also present, and usually in sufficient amounts; but generally there are also present considerable quantities of readily soluble mineral salts, which may be, and often are, a serious detriment to plant growth, and it is these excessive amounts of soluble salts which command more immediate attention. Nevertheless, the chemical and physical phenomena presented by soils both from the arid and humid regions are essentially the same.

From their nature soils from the humid areas present analytical and mechanical obstacles which make the study of the ground solutions in them exceedingly difficult. On the other hand, these difficulties are much less with soils from the arid regions. It is natural and proper, therefore, that the study of the soils of the arid regions should develop more rapidly and precede the study of the soils of the humid regions, and that the general features of the problems involved should be mastered in the former study, before applying the methods there worked out to the latter study. The attempt is now being made in the laboratories of this Division to study certain soils from humid areas according to the ideas which have been developed in the investigation of alkali soils, and it is believed with a gratifying promise of success.

The presence of soluble carbonates or, more probably, hydrogen carbonates is to be expected in all soils. In humid soils they are present only in very small amounts, and their characteristic properties are generally more or less masked by the presence of an excess of dissolved carbon dioxide or carbonic acid in the soil solutions. The soil atmosphere has been shown to be unusually rich in carbon dioxide—certainly as compared with the atmosphere above the soil—and this is true even in well-drained and well-aerated soils, so that considerable amounts of dissolved carbon dioxide are to be expected in the soil solution, since the solubility of the substance is dependent upon the partial pressure it exerts in the gas phase or atmosphere in contact with the solution.

In arid regions the amounts of soluble normal carbonates and hydrogen carbonates in the soil are occasionally quite large. It has been suspected for some time that the normal carbonates and hydrogen carbonates play quite a different rôle in their relations to crop culture, as well as to the other soil components. These suspicions have been confirmed by laboratory investigations and field observations. It has become an economic necessity, therefore, to distinguish between the normal carbonates and the hydrogen carbonates present in the soil, in irrigation and drainage waters.

The relative amounts in which the normal carbonates and hydrogen carbonates will be present in a solution are naturally dependent upon one another and upon certain other factors, including temperature, composition of the atmosphere in contact with the solution, etc. The carbonates and hydrogen carbonates of the alkali metals and alkali earth metals have many features in common when in aqueous solution, but they also present well-marked differences.

While these facts were more or less clearly realized, our knowledge of them and of the mutual relations between them was too indefinite and uncertain to explain satisfactorily, even in a qualitative way, the phenomena observed in the field work. Even less was this knowledge sufficient to enable one to predict the changes in the soil solutions with changing conditions. That such knowledge would have an immense importance in an intelligent use and control of irrigating waters in lands containing soluble carbonates is self-evident. Some idea of the probable modifications which will occur in such soils can now be formed on the basis of the investigation here recorded on the equilibrium between normal carbonates and hydrogen carbonates in aqueous solutions. The effect of drainage upon such lands can now be predicted with some confidence. Incidentally, much information of importance in studying geological as well as soil problems has been brought out. It seems certain, moreover, as Dr. Cameron points out, that the data presented may find a large usefulness in certain technical processes involving the manufacture or employment of alkali carbonates.

It has been pretty definitely shown that the predominating chemical feature of most, if not all, alkali regions is the interaction of certain soluble salts in aqueous solutions upon less soluble salts—notably gypsum ($CaSO_4.2H_2O$) and calcium carbonate ($CaCO_3$). While certain general features of such systems could be recognized on the basis of the electrolytic dissociation hypothesis, practically no precise knowledge was available. It was essential for a correct understanding of the phenomena that they should be studied in the laboratory under conditions which are simpler and more readily controlled than those that usually obtain in the field.

The solubility curves established in the investigations here recorded have brought out several facts which were quite unforeseen and which have a great importance in the study and control of alkali soils. The time is surely approaching, if it has not already arrived, when the agriculturist in the arid regions will demand further assistance than the information that his soils need irrigation or underdrainage or both. He has a right to expect expert opinion as to the probable specific effects of such treatment on his soils. The importance of calcium in the soil solutions in enabling crops to withstand excessive amounts of other salts is but one of the many factors which is becoming recognized. The relative proportions in which the different base-ions and acid-ions occur in the soil solutions in relation to their adaptability for various crops—and will occur after cultivation and irrigation—is becoming more evidently important as the study of soil solutions proceeds.

The transportation of gypsum and lime carbonate in the soil and their reprecipitation, sometimes in porous layersand sometimes as a detrimental hardpan, is of great economic importance. The use of gypsum or land plaster on soils containing carbonates has long been known, but its rationale has needed clearing up. Incidentally, it has been pretty clearly indicated that the application of calcium sulphate to other classes of soils may have economic results of considerable value.

The solubility determinations described in this Bulletin are fundamental and necessary to a successful investigation of such questions. Not the least of their uses is in pointing out a line of attack upon the exceedingly difficult and perplexing problem of the use of mineral fertilizers upon the soils of humid regions. Their importance in certain geological problems needs no further comment.

Analytical investigations of alkali soils have been numerous, and nearly as numerous have been the procedures and methods employed. This state of affairs presents the very unfortunate feature that the work of various investigators, no matter how valuable it may be in itself, can not be intelligently used in comparative studies. Considerable attention has been given to this subject, and a method of procedure has been developed in the laboratory of this Division which it is believed will give more rational results than any other yet proposed, and which in its salient features, if not in its entirety, must ultimately be adopted by investigators in this field by general convention. It presents some arbitrary features, necessitated by the limitations of our knowledge, but it is believed to be as free from objections on this score as is now possible. A detailed description of this analytical scheme has therefore been prepared for this Bulletin and also an account of the development of the method now used in the work of this Division for the field estimation of carbonates, bicarbonates, and chlorides—with certain extensions and modifications for particular conditions.

MILTON WHITNEY.

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SOLUTION STUDIES OF SALTS OCCURRING IN ALKALI SOILS.

EQUILIBRIUM BETWEEN CARBONATES AND BICARBONATES IN AQUEOUS SOLUTION.

By **Frank K. Cameron** and **Lyman J. Briggs.**

STATEMENT OF THE PROBLEM.

If an aqueous solution of sodium carbonate be allowed to come to equilibrium in contact with the air, there is always formed a greater or less amount of the hydrogen carbonate, more generally known as bicarbonate.

The system is then quite complex; for, in addition to the normal carbonate and the hydrogen carbonate, there is present also sodium hydroxide from the hydrolysis of the salt, dissolved carbon dioxide, possibly carbonic acid, and the various electrolytic dissociation products. If the sodium hydrogen carbonate be considered alone, the concentration of the solution with respect to this salt will be dependent upon several factors.

(1) It is obviously dependent on the amount of normal sodium carbonate present, for it is one of the products resulting from the hydrolysis of that substance, as is indicated by the scheme

$$Na_2CO_3+HOH\rightleftarrows NaOH+NaHCO_3$$

(2) It will depend obviously upon the temperature, for the amount of hydrolysis of the normal carbonate is dependent upon the temperature. Further, the amount of carbon dioxide and, in consequence, the carbonic acid in the solution is a function of the temperature.

(3) It will depend upon the partial pressure of carbon dioxide in the vapor phase in contact with the solution; that is to say, upon the amount of carbon dioxide per unit volume in the atmosphere above the solution. Upon this partial pressure in the vapor phase will depend the amount of the carbon dioxide dissolved in the solution and obviously the amount of the normal carbonate which will be converted by it to the hydrogen carbonate. Further, sodium hydrogen carbonate, being a salt composed of a strong base in contact with a weak acid, would be hydrolized unless the hydrolysis be forced back by an

excess of the weak acid in solution. Walker and Cormack[1] have shown that the ions resulting from the solution of carbon dioxide in water are mainly $\overset{+}{H}$ and $\overline{HCO_3}$, and to a very much less extent the ion $\overline{\overline{CO}}_3$. More recently Bodlander[2] has shown that the dissociation, with formation of $\overline{HCO_3}$ ions is about twenty thousand times as great as with the formation of $\overline{\overline{CO}}_3$ ions.

Supposing the temperature to remain constant, and omitting the formal statement of the details, these facts might be schematically arranged thus:

$$NaHCO_3 \begin{cases} \longleftrightarrow Na_2CO_3 \\ \longleftrightarrow H.HCO_3 \longleftrightarrow CO_2 \text{ (vapor phase)} \end{cases}$$

where the double-headed arrow is taken to mean "is dependent upon." This schematic arrangement indicates that if some effective means were devised by which the carbon dioxide could be removed from the vapor phase as fast as it was formed, it would be possible to gradually remove all carbonic acid from the system and ultimately a solution of sodium hydroxide alone would remain. The experimental difficulties in the way of accomplishing this would undoubtedly be great and, as the matter does not appear to be of any practical importance, no attempt has been made to realize it.

RELATION OF THE PROBLEM TO SOIL STUDIES.

The problem of the relation of normal carbonates to the corresponding hydrogen carbonates possesses much practical interest. In the investigation of "black alkali" in the soils of arid regions it is of fundamental importance, for wherever the sodium carbonate is found the soil solution will also necessarily contain a greater or less amount of the hydrogen carbonate. Investigation in this Division has shown the latter salt (hydrogen carbonate) to be an injurious one to plant growth, but vastly less so than the normal carbonate.

A study of the recent observations of our field parties indicates that it is feasible to so modify black alkali conditions that the normal sodium carbonate can be reduced to a very low minimum by conversion to the less noxious hydrogen carbonate, this conversion depending in part upon the fact that the soil atmosphere invariably contains a relatively high percentage of carbon dioxide.[3] This point will be referred to again.

While the amount of carbon dioxide in the soil atmosphere is always greater than in the air, it probably varies much with different soils and for any given soil under varying conditions. Our information on this point is very meager, although sporadic attempts have been made to obtain measurements in this direction from the time of Bouissangault and Lewey[1] to the present. It has seemed wise in this preliminary study, therefore, to investigate the equilibrium of the system in contact with ordinary air. It is thus possible to have a vapor phase in which the partial pressure of carbon dioxide is very constant; and, moreover, it represents the maximum condition possible in nature for the concentration with respect to the normal carbonate; that is to say, the limit beyond which no worse conditions for plant growth can exist.

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[1] Jour. Chem. Soc., **47**, 5 (1900).

[2] Zeit. für phys. Chem., **35**, 25 (1900).

[3] The absorption of carbon dioxide by soils will be fully discussed by Briggs in a publication of this Division to appear at an early date.

DISTINCTION BETWEEN CARBONATES AND BICARBONATES.

The investigation has been made readily feasible by a method, recently devised in this Division, for the estimation of carbonates (with the hydrolized sodium hydroxide) and bicarbonates when both are in the solution simultaneously.[2] The method is based primarily upon the fact that carbonic acid is a stronger acid than phenolphthalein, and that the hydrolysis of the carbonate proceeds at a moderately rapid rate. It is therefore possible to continue titration with hydrogen potassium sulphate solution until there is no normal carbonate remaining in the solution. By then adding methyl orange, an acid indicator stronger than carbonic acid, the titration can be continued and the total amount of the base constituent present thus determined. From these data it is a simple matter, as will be pointed out elsewhere, to compute the amount of normal carbonate and hydrogen carbonate present.

It will be convenient to consider the system we are studying as made up of the normal carbonate and the hydrogen carbonate with this method of estimating them as the criterion between them. The normal carbonate, together with the hydrolized hydrate, will be considered under the head of normal carbonate—in contradistinction to the hydrogen carbonate which is present before the titration of the solution is commenced.

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[1] Johnson (How Crops Feed, p. 139), quoting from the investigations mentioned, gives the following figures:

	CO_2 in 10,000 parts, by weight.
Air from sandy subsoil of forest	38
Air from loamy subsoil of forest	124
Air from surface soil of forest	130
Air from surface soil of vineyard	146
Air from pasture soil	270
Air from soil rich in humus	543

[2] See paper on "Estimation of Carbonates and Bicarbonates," page 77.

EXPERIMENTS WITH SODIUM SALTS.

Solutions of sodium carbonate of various concentrations were prepared, about 200 cubic centimeters of each solution being brought into a small flask. The flasks were connected in series by a system of stoppers and tubing and were immersed in a bath the temperature of which could be closely regulated by a thermostat. Air which had previously been passed through a wash flask, containing water slightly acidulated with sulphuric acid, was then drawn continuously by means of an aspirator through the series of flasks for lengths of time varying from four days to several weeks, depending upon what was shown by experience to be necessary to bring about a state of complete equilibrium. The solutions were then removed from the bath one by one, an aliquot portion carefully measured off by running it from a burette, and the titrations made as promptly as possible with N/10 $HKSO_4$ solution.[1]

In the accompanying tables (I, II, III, and IV) the first column gives the number of gram atoms of sodium per liter; the second column, the number of cubic centimeters of solution taken for the titration; the third and fourth columns, the number of cubic centimeters of acid solution required in the titrations; the fifth column, the percentage of the base combined as normal carbonate and its hydrolized product—the hydrate; the sixth column, the percentage of the base combined as the hydrogen carbonate.

TABLE I.—*System: Na_2CO_3, $NaHCO_3$, and CO_2.*

TEMPERATURE 25° C.

Concentration gram atoms Na.	Amount solution titrated.	Amount $HKSO_4$ required.		Amount sodium combined.	
		With ph. phth.	With meth. or.	As Na_2CO_3.	As $NaHCO_3$.
	c. c.	c. c.	c. c.	*Per cent.*	*Per cent.*
0.0044	50	0.10	2.3	8.7	91.3
	50	.10	2.3		
.0143	20	.30	3.0	20.0	80.0
	20	.30	3.0		
.0562	10	1.10	5.9	37.3	62.7
	10	1.10+	5.9		
.2248	10	7.0	23.6	59.3	40.7
	10	7.0	23.6		
.8847	2	6.15	18.65	64.0	36.0
	2	5.90	18.50		
	3	9.00	27.90		

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[1] A solution containing 13.516 grams $HKSO_4$ per liter. The assumption is specifically made that the substance is a monovalent acid.

TABLE II.—*System:* Na_2CO_3, $NaHCO_3$, *and* CO_2.

TEMPERATURE 37° C.

Concentration gram atoms Na.	Amount solution titrated.	Amount HKSO$_4$ required.		Amount sodium combined.	
		With ph. phth.	With meth. or.	As Na_2CO_3.	As $NaHCO_3$.
	c. c.	*c. c.*	*c. c.*	*Per cent.*	*Per cent.*
0.0019	50	0.05	0.95	10.5	89.5
	50	.05	.95		
.0071	20	.15	1.45	21.1	78.9
	20	.15	1.40		
.0276	10	.55	2.75	41.3	58.7
	10	.60	2.78		
.1030	10	3.35	10.30	64.5	35.5
	10	3.30	10.30		
.421	2	3.50	8.45	81.9	18.1
	2	3,40	8.40		
.815	2	7.0	16.4	86.5	13.5
	2	7.1	16.2		
1.795	2+	15.1	36.1	83.4	16.6
	2	14.85	35.65		

TABLE III.—*System:* Na_2CO_3, $Na\ HCO_3$, *and* CO_2.

TEMPERATURE 50° C.

Concentration gram atoms Na.	Amount solution titrated.	Amount HKSO$_4$ required.		Amount sodium combined.	
		With ph. phth.	With meth. or.	As Na_2CO_3.	A $NaHCO_3$.
	c. c.	*c. c.*	*c. c.*	*Per cent.*	*Per cent.*
0.0017	50	0.1	0.9	22.2	77.8
	25	.05	.45		
.0071	20	.25	1.50	32.9	67.1
	20	.25	1.55		
.0266	10	.7	2.80	50.7	49.3
	20	1.45	5.65		
.1014	10	3.7	10.6	70.0	30.0
	10	3.75	10.7		
.4066	10	17.1	42.3	81.0	19.0
	2	3.5	8.6		
.8068	2	7.2	16.5	86.8	13.2
	2	7.0	16.15		
1.7486	2.1	15.9	36.5	87.1	12.9
	2	15.2	35.0		

TABLE IV.—*System:* Na_2CO_3, $NaHCO_3$, *and* CO_2.

TEMPERATURE 75° C.

Concentration gram-atoms Na.	Amount solution titrated.	Amount HKSO$_4$ required—		Amount sodium combined.	
		With ph. phth.	With meth. or.	As Na_2CO_3.	As $NaHCO_3$.
	c. c.	*c. c.*	*c. c.*	*Per cent.*	*Per cent.*
0.003	50	0.2—	1.4	25.7	74.3
	25	.1	.7		
	25	.08	.7		
.019	20	.3	1.75	34.8	65.2
	20	.3	1.70		
.036	10	.9	3.3	55.7	44.3
	10	.95	3.35		
.270	5	4.9	12.5	79.5	20.5
	5	5.0	12.4		
.702	1	2.7	6.45	85.0	15.0
	1	2.75	6.5		
6.56	1	25.8	60.0	84.8	15.2
	1	25.5	61.0		

The results given in these tables are graphically presented in fig. 1. It will be observed that the curves are all of the same general nature, that is, with increasing concentration the proportion of normal carbonate rapidly increases at first, but soon comes almost to a maximum and from that point on there is a very small increase in the proportion of normal carbonate with an increase in the total concentration. The higher the temperature the more nearly does the flat part of the curve lie parallel to the axis of abscissas, until at 100° C. practically the whole length of the curve is exactly horizontal to it. The curve plotted from the data obtained at 75° C. lies so close to that for 50° C. that it is not practicable to distinguish it from the latter on a chart of the scale represented in our figure.

For any given concentration the proportion of normal carbonate increases with the temperature, until at 100° C. for almost all concentrations the percentage of normal carbonate is practically 100; for 25° about 50 per cent of the sodium is in the form of normal carbonate when the total concentration is 0.12 to 0.13 gram-atoms of sodium per liter; with a concentration of 0.4 gram-atoms of sodium per liter about 63 per cent of the sodium is in the form of the normal carbonate; and there is a gradual increase from this point on, until at a concentration of 0.89 gram-atoms of sodium per liter about 64 per cent of the sodium is in the form of normal carbonate, and at a concentration of 8.0 gram-atoms of sodium about 86 to 87 per cent of the sodium is in the form of the normal carbonate. Similar data can readily be obtained for the other temperatures by interpolation on the charted curves.

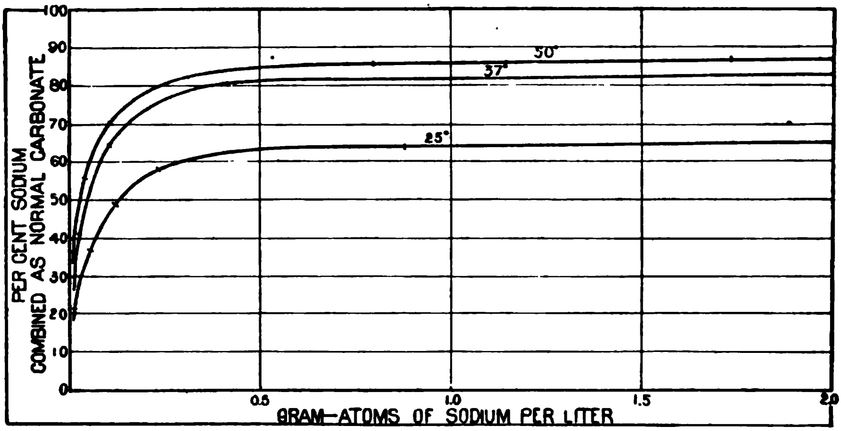

FIG. 1.—Diagram showing percentage distribution of sodium as carbonate and bicarbonate, at different concentrations and temperatures.

A curious fact brought out by an inspection of the chart is, that at all temperatures there is a rapid increase in the percentage of normal carbonate up to a concentration of about 0.4 gram-atoms of sodium per liter, and from this point on the percentage of normal carbonate increases very slowly; that is to say, a change from a rapid to a slow increase in the percentage of normal carbonate with increasing concentration comes at about the same concentration, irrespective of the temperature, at least below 75° C. What special significance, if any, this may have is not apparent at present.

By referring to Table IV it will be observed that in the solution containing 6.56 gram-atoms of sodium per liter there appeared to be actually a lesser percentage of the normal carbonates than in the solution containing 0.7 gram-atoms of sodium per liter. At first it was supposed that this indicated a faulty determination of the carbonates, and that the true interpretation of the result was that beyond a concentration of 0.7 gram-atoms of sodium per liter the curve for 75° C. was practically horizontal to the axis of abscissas. It appeared later, however, that in all probability, and at all temperatures, there is a maximum point on the curve beyond which there is an actual falling off in the percentage of normal carbonate with increased concentration of the solution. It is not possible to offer an explanation for this phenomenon at present, but it is intended to give the subject further attention at some future time.

It was hoped that possibly an approximation to the amount of hydrolization of sodium carbonate in solutions of varying concentration might be made from our results, by considering the amount of the hydrogen carbonate formed from the dissolved carbon dioxide as small and constant in amount on account of the small and constant partial pressure of this latter substance in the vapor phase. The nature of the curves at the lower concentrations, however, show conclusively that no such assumption can be made and that the influence of the dissolved carbon dioxide can not be disregarded. If the hydrolysis of the sodium carbonate be supposed to take place according to the scheme

$$Na_2CO_3 + HOH \rightleftarrows NaOH + NaHCO_3$$

then there must necessarily be as many reacting weights of sodium hydroxide in the solution as there are reacting weights of sodium hydrogen carbonate. But the curves vary continuously and without breaks, until at infinite dilution there is 100 per cent of the sodium in the form of hydrogen carbonate present and no sodium in the form of hydrate or normal carbonates. It is therefore apparent that the influence of the dissolved carbon dioxide, even though it be quite small in amount, can not be neglected, and the attempt to get a measure of the hydrolysis from the date here presented is vain. It may afford an explanation in part of why Walker and Cormack[1] found such a large proportion of HCO_3 ions as compared with CO_3 ions in their dilute solutions, and is probably the reason why they did not observe any hydrolysis of sodium hydrogen carbonate in dilute solutions.

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[1] Loc. cit.

The data contained in Table I have been recalculated and are presented in Table V in another form. The first column gives the concentration in grams per liter with respect to the sum of the weights of normal carbonate and bicarbonate present; the second and third columns give the weight per liter and the percentage of normal carbonate present; the fourth and fifth columns, the corresponding data for the bicarbonate or hydrogen carbonate.

TABLE V.—*System:* Na_2CO_3, $NaHCO_3$ *and* CO_2.

TEMPERATURE 25° C.

Total salts dissolved.	Na_2CO_3.		$NaHCO_3$.	
	Weight.	Per cent.	Weight.	Per cent.
Grams.	*Grams.*		*Grams.*	
0.3555	0.0203	5.71	.3352	94.29
1.1053	.1505	13.62	.9548	86.38
4.0443	1.1041	27.30	2.9402	72.70
14.6558	7.0212	47.91	7.6346	52.09
56.3982	29.8223	52.88	26.5759	47.12

In fig. 2 these data are graphically presented, the ordinates representing the percentage of normal carbonate present and the abscissas the concentration with respect to the total salts present.

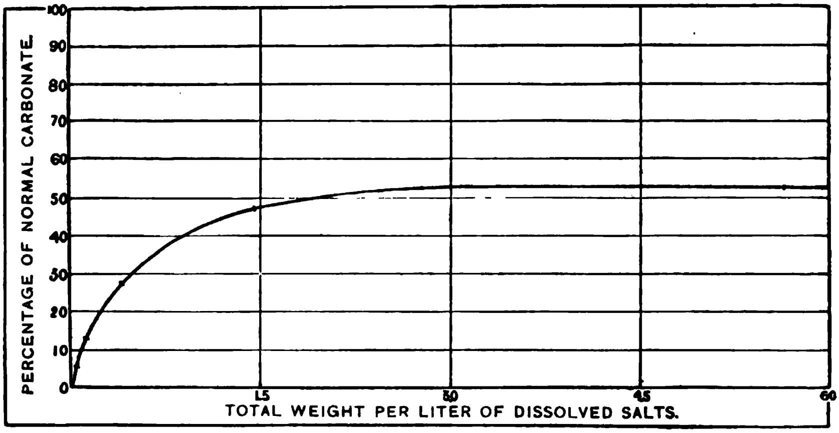

FIG. 2.—Diagram showing amounts of normal carbonate in solutions of the carbonate and bicarbonate of sodium.

An inspection of this curve shows that at 25° C. there are equal weights of sodium carbonate and sodium hydrogen carbonate in a solution in which the total weight of both salts is approximately 21.6 grams per liter, or 10.6 grams per liter of each. Even with a concentration with respect to both salts of 60 grams to the liter the amount of normal carbonate rises only to about 53.5 per cent of the total weight of the two salts present. The data obtained at 25° C. are presented in this form because it is much easier to make comparison with the data obtained in our experience in dealing with samples of alkali soils and crusts, sent to the Division for examination, and with samples of water obtained from alkali areas. It is not proposed to go into this comparison in detail here. It will be discussed by Mr. Gardner[1] in connection with his work on the alkali areas in Utah. Suffice it to say that the results presented in this paper are very closely in accord with the data obtained from the experience of our field parties.

It has been amply demonstrated by Mr. Gardner that in the surface alkali of the Sevier Valley, Utah, the proportion of bicarbonate or hydrogen carbonate to normal carbonate is greatly increased as the total amount of these salts decrease. This same experience holds also for other cases, although it has not received such marked attention elsewhere. Further, an examination of the analytical results for the river water and the canal waters in the Sevier Valley shows results in very close accord with what would have been predicted on the basis of the work here described. It should be remembered, however, that the partial pressure of the carbon dioxide in the soil atmosphere is probably always greater, and generally much greater, than in the air. For this reason the equilibrium between the normal carbonate and hydrogen carbonate is displaced in the direction of the formation of more hydrogen carbonate, so that seepage water or spring water fresh from the soil will contain at first, or until sufficient time has elapsed for the solution to come to equilibrium with the air, much greater percentages of the hydrogen carbonate than our curve would indicate.

EXPERIMENTS WITH POTASSIUM SALTS.

In Table VI are given the results obtained from a series of experiments upon the equilibrium between the normal carbonate and hydrogen carbonate of potassium at 25° C. The increase of the percentage of normal carbonate with increasing concentration of potassium is not quite so rapid as in the case of the sodium salts for the lower concentrations, but is more rapid for higher concentrations than is the case with the sodium salts. The examination was extended to solutions of a higher concentration in this case to settle definitely the question of the existence of a maximum point in the curve. It unquestionably exists somewhere in the neighborhood of a concentration of two reacting weights of potassium per liter; beyond this point there appears to be a very gradual diminution of the percentage of normal carbonate.

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[1] Report, Field Operations of the Division of Soils for 1900, U. S. Dept. of Agr.

Table VI.—*System: K_2CO_3, $KHCO_3$, and CO_2.*

TEMPERATURE 25° C.

Concentration, gram-atoms K.	Amount solution titrated.	Amount $HKSO_4$ required—		Distribution of potassium.	
		With ph. phth.	With meth. or.	As K_2CO_3.	As $KHCO_3$.
	c. c.	*c. c.*	*c. c.*	*Per cent.*	*Per cent.*
0.393	5	7.6	19.6	77.5	22.5
	5	7.65	19.75		
.553	2	4.75	11.0	83.9	16.1
	5	11.25	27.8		
1.025	2	8.9	20.5	86.8	13.2
	2	9.1	20.8		
	2	8.8	20.2		
1.865	2	17.1	37.1	91.4	8.6
	2	17.0	37.5		
2.820	2	25.2	56.4	89.0	11.0
	2	25.1	56.3		
3.710	2	33.15	74.2	88.6	11.4
	2	32.9	74.6		
4.31	1	19.3	43.0	89.6	10.4
	1	19.3	43.2		
5.605	1	25.25	56.9	88.7	11.3
	1	25.3	57.0		

The last two determinations given in the table do not appear quite consistent with the others. They were made subsequently to the others, smaller quantities of the solution being taken for the titrations and no special care being exercised to obtain great accuracy, as they were made solely for the purpose of establishing the fact that a maximum point would really exist on the curve. In a general way the phenomena presented by the potassium salts were so closely analogous to those presented by the sodium salts that it was not deemed advisable, from press of time, to continue the investigation of the former at higher temperatures at present.

THE CALCIUM SALTS.

The solubility of calcium carbonate in pure water at 16° C. is, according to Schlösing[1], about 0.0131 grams per liter. In such a solution Bodländer[2] has shown that in all probability about 80 per cent of the salt is hydrolized and dissociation is so complete that practically all the calcium in the solution is in the form of ions. With the addition of carbon dioxide to the vapor phase, however, the solubility of the calcium carbonate is much increased, owing to the formation of the more soluble calcium hydrogen carbonate. According to Schlösing[3], at a partial pressure for the carbon dioxide in the gas phase of 0.9841 atmospheres, and at a temperature of 16° C., the solubility is increased so that there is the equivalent of 1.086 grams per liter of calcium carbonate in the solution. Treadwell and Reuter[4] found that at 15° C. and under a partial pressure of the carbon dioxide in the gas phase equal to an atmosphere, the material dissolved was equivalent to 1.156 grams of calcium carbonate per liter. Under such conditions there could be no hydrolysis of the salts, and in the case of Treadwell and Reuter's experiment all the dissolved material must have been in the form of the hydrogen carbonate. The solubility of the calcium is certainly increased nearly ninety times.

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[1] Compt. rend., **74**, 1552 (1872).

[2] Zeit. für phys. Chem., **35**, 28 (1900).

[3] Compt. rend., **75**, 70 (1872).

[4] Zeit. für anorg. Chem., **17**, 178 (1898).

In the case of soil solutions the partial pressure of the carbon dioxide must be somewhere between the limits 0.0 and one atmosphere, and the solubility of calcium carbonate will be somewhere between the extremes noted above. An approximation to its solubility in solutions in contact with the air can be obtained from Schlösing's figures. This authority found that at 16° C., and a pressure for the carbon dioxide equal to 0.000504 atmospheres, the solubility was 0.0746 grams per liter—calculating the salt as normal carbonate—or in effect the solubility is nearly six times what it would be in pure water.

But another aspect of the question must be borne in mind in this connection. Treadwell and Reuter have definitely shown that calcium hydrogen carbonate in aqueous solution is a rather stable compound, at least at 15° C., and that it does not always decompose at once with the partial inversion to the normal carbonate as the partial pressure of the carbon dioxide in the vapor phase is lowered. They found that after reducing the partial pressure of the carbon dioxide in the gas phase to zero, there remained no free carbon dioxide in the solution, but that the solution still contained an amount of calcium, entirely in the form of hydrogen carbonate, equal to 0.3850 grams per liter of this salt. This would be equivalent to 0.2380 grams per liter of the normal carbonate or 18.16 times the amount found soluble in pure water by Schlösing. Therefore the origin and past history of a solution is of the utmost importance in considering its concentration with respect to calcium carbonate or hydrogen carbonate. For example, a solution which has been formed in a soil in which there is a large amount of carbon dioxide, and which subsequently comes to equilibrium with the air, may well be very different in concentration from a solution which was formed directly in contact with the air. It is probable, however, that with agitation of the solution, such as would occur in a turbulent stream, for example, the stability of the calcium hydrogen carbonate would be considerably lessened, and that it would partially decompose, the concentration being reduced to the point which would result from the solution of calcium carbonate by water in contact with air.

The experiment has been made in the laboratory of this Division of preparing two solutions of calcium carbonate—one made by dissolving the calcium carbonate in distilled water from which the dissolved carbon dioxide has been expelled by boiling, the other by dissolving the salt in distilled water containing somewhat more carbon dioxide than would be dissolved from the air. A few drops of alcoholic solution of phenolphthalein were added to each. The first showed an intense red color, but the second showed no color, indicating that there was practically no hydrolized base in the solution. A current of air was passed through both solutions continuously for three days. Aliquot portions of both solutions gave practically identical results for calcium determinations. After the passage of the air through the solutions had been stopped they both showed a faint trace of pink color on the addition of phenolphthalein. The amount of material in solution was so small that it did not seem worth while to attempt very accurate measurements, but the mean of two closely agreeing series of titrations indicated that at 30° C. in equilibrium with the air not more than 3 per cent of the calcium present could be combined as normal carbonate. At lower temperatures and lesser concentrations the percentage of normal carbonate must be even less. It did not seem advisable, therefore, to attempt any further study of the distribution of the base calcium between the normal carbonic acid and the hydrogen carbonic acid in solutions of these salts in equilibrium with atmospheric air, or in equilibrium with a gas phase containing a larger proportion of carbon dioxide than ordinary air.

The facts just presented are of very great importance in geological and soil studies, for it is evident that with solutions such as we have been discussing one is dealing almost entirely with calcium hydrogen carbonate; and in the reactions with other electrolytes which may come into the solution it is the hydrogen carbonate which must be considered.

Another interesting point is that although a solution may be holding as much of this salt as is possible under existing conditions it can not be considered as saturated with respect to it, for it may be able to take up more of the salt by increasing the partial pressure of the carbon dioxide in the gas phase. It would be interesting to know what the absolute solubility of calcium hydrogen carbonate is for some temperatures. It is probable that it is considerable in amount, and it is not so surprising that deep-seated waters are able to carry such relatively large quantities of this salt. The much increased solvent action of waters carrying much dissolved carbon dioxide upon calcium-bearing rocks is readily intelligible in the light of these facts.

THE MAGNESIUM SALTS.

The solubility of magnesium carbonate in pure water at 12° C. is given by Engel[1] as 0.970 grams per liter. Treadwell and Reuter[2] found the solubility at 15° C., in contact with a vapor phase in which the partial pressure of the carbon dioxide had been reduced to zero, to be about 0.627 grams per liter. These investigators found that under a partial pressure for the carbon dioxide equal to one atmosphere there was in solution 12.105 grams per liter of the magnesium hydrogen carbonate—equivalent to 6.977 grams per liter of the normal carbonate. Unlike the corresponding calcium salt, they found the magnesium hydrogen carbonate to be very unstable, and that all the magnesium could remain in the form of this salt only when there was a considerable excess of carbon dioxide dissolved in the solution.

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[1] Compt. rend., **100**, 144 (1885); Ann. Chim. et Phys. (6), **13**, 349 (1888).

[2] Zeit. für anorg. Chem., **17**, 199 (1898).

Every investigator who has attempted to study magnesium carbonate in solution has experienced very great experimental difficulties. There is good reason to believe, as Bodländer[1] has pointed out, that these difficulties are due to the formation of complex molecular species $n\text{Mg}(\text{OH})_2\, m\text{MgCO}_3$, with complex ions, resulting in the presence of considerable quanties of hydroxyl ions in the solution. This is tantamount to saying that there is considerable hydrolized normal carbonate in the solution—a fact which is apparent when one adds phenolphthalein to a solution of magnesium carbonate.

In saturated solutions of magnesium carbonate the formation of these complex compounds is of undoubted importance, and their study, as has been said above, is exceedingly difficult. In all probability they are mainly responsible for the discrepancies in the observations of various investigators of this subject. But in solutions of lesser concentration, and especially when there is some excess of dissolved carbon dioxide, they do not assume any practical importance even if they have an actual existence under such circumstances. To all intents and purposes the solution may be considered as containing only the solutes normal magnesium carbonate (with the hydrolized free base) and magnesium hydrogen carbonate. It appears worth while, therefore, to get some idea as to the distribution of the base between the two acids by the method described in connection with the work on the sodium salts. The results are given in Table VII, which is self-explanatory.

TABLE VII.—*System: $MgCO_3$, $Mg(HCO_3)_2$ and CO_2.*

TEMPERATURE 30° C.

Total Mg (grams per liter).	Mg as $MgCO_3$ (grams per liter).	Mg as $Mg(HCO_3)_2$ (grams per liter).
0.02410	0.01205	0.01205
.13135	.06820	.06314
.16087	.08676	.07411

Total Mg (gram atoms per liter).	Mg as $MgCO_3$.	Mg as $Mg(HCO_3)_2$.
	Per cent.	*Per cent.*
0.00100	50.00	50.00
.00545	51.92	48.08
.00667	53.93	46.07

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[1] Zeit. für phys. Chem., 35, 31 (1900).

Table VII.—*System:* $MgCO_3$, $Mg(HCO_3)_2$ *and* CO_2—Continued.

TEMPERATURE 30° C.

Total salts in solution (grams per liter).	Normal carbonate.		Hydrogen carbonate.	
	Grams per liter.	Per cent.	Grams per liter.	Per cent.
0.1144	0.0418	36.5	0.0726	63.5
.6174	.2368	38.2	.3806	61.7
.7479	.3012	40.3	.4467	59.7

Assuming that at infinite dilution all the magnesium will be in the form of hydrogen carbonate, it is evident that the curve for the more dilute solutions is much steeper than the curve for the corresponding concentrations with respect to the sodium salts. But the general nature of the curve will be the same, the upper part being very flat. It would appear probable, therefore, that in all solutions of the magnesium salts with which one has to deal practically, and which are in equilibrium with the air but not in contact with the magnesium carbonate in the solid phase, about 50 per cent (in round numbers) of the magnesium is in the form of the normal carbonate. Solutions of the magnesium salts are therefore in strong contrast to solutions of the calcium salts where practically all the base is combined in the form of the hydrogen carbonate.

But in contact with the magnesium carbonate in the solid phase quite different conditions may obtain when there is also an excess of carbon dioxide in the solution. Some carefully prepared magnesium carbonate was suspended in distilled water and a current of air, which had previously been washed in a dilute solution of sulphuric acid, was passed through continuously for twenty-nine days. The solution then contained 0.1530 gram of magnesium per liter, of which 0.0446 gram of magnesium per liter, or 29.1 per cent of the total, were in the form of the normal carbonate. The current of air was then passed through the solution for seventeen days longer. The solution then contained 0.1837 gram per liter of magnesium, of which 0.0542 gram, or 29.5 per cent, were in the form of normal carbonate. The flask containing the solution and suspended solid magnesium carbonate was then put aside for fifty-four days longer. The solution was then found to contain 0.1808 gram of magnesium per liter, of which 0.0615, or 33.9 per cent, were combined as normal carbonate.

The total amount of magnesium in the solution, as shown by the last determination, is equivalent to 0.6276 gram normal carbonate per liter, which agrees with the figure (0.627) obtained by Treadwell and Reuter,[1] although the mean temperature of the solution in the experiments here described was about 22° C. instead of 15° C., the temperature at which the investigators quoted worked. Moreover the solution of

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[1] Zeit. für anorg. Chem., 17, 199 (1898).

Treadwell and Reuter was supposed to contain no free carbon dioxide or carbonic acid.

From the data which have been presented above, it would appear that in a solution near the saturation point and in equilibrium with atmospheric air, upwards of 50 per cent of the magnesium would be in the form of the normal carbonate. When the solution was brought in contact with the salt in the solid phase and allowed to remain in equilibrium with atmospheric air more of the substance would go into solution (as the hydrogen carbonate) until the proportion of the base combined as normal carbonate would fall to about 34 per cent or lower. These facts are of the utmost importance in the consideration of "alkali" problems, for there is evidently a marked difference in this respect as well as in total solubility between the carbonates of calcium and of magnesium. It seems probable, therefore, that the presence of much magnesium carbonate, as compared with calcium carbonate, in the soil would have a much more marked effect in producing soluble normal carbonates or the dreaded "black alkali." These views appear to be in perfect accord with the observations of the field parties of this Division. It should be borne in mind that soil solutions in general carry much more dissolved carbon dioxide or carbonic acid than solutions in equilibrium with atmospheric air; and in such solutions the relative percentage of the magnesium in the form of normal carbonate may well be much less than what has just been considered in the foregoing paragraphs.

Another point to which it seems worth while to call attention here, and which is well illustrated by the experiments described above, is the comparatively long periods of time required to bring a solution to equilibrium with a solute in the solid phase, when the solute is sparingly soluble. Attention has been called to this in connection with some other investigations made in this Division, and it must be insisted that this is an important matter in considering soil phenomena, although a factor most difficult to control and for which to make proper allowance.

SUMMARY.

From the facts presented in this paper the following conclusions are drawn:

1. When in equilibrium with air every aqueous solution of sodium normal carbonate contains necessarily some sodium hydrogen carbonate. And, conversely, every solution of sodium hydrogen carbonate contains necessarily some normal sodium carbonate. At equilibrium there is a definite distribution of the base between the two acids.

2. The equilibrium is conditioned by the concentration, the temperature, and the partial pressure of the carbon dioxide in the vapor phase.

3. At any given concentration the proportion of normal carbonate

increases with rise of temperature. Conversely at any given temperature the proportion of normal carbonate increases with the total concentration except at any great concentration.

(4) The phenomena presented by the solutions of the carbonate and hydrogen carbonate of potassium are strictly analogous to those presented by the sodium salts, differing only in the quantitative relations.

(5) Above some concentrations, relatively large, there is a gradual diminution of the percentage of normal carbonate; that is, there is an actual maximum point to the curve. The significance of this maximum point is not understood at present.

(6) It seems improbable that more than 3 per cent of the calcium is ever combined as the normal salt in solutions of the carbonates of this base when in contact with a vapor phase containing as much or more carbon dioxide than atmospheric air. Practically one has to consider only solutions of the hydrogen carbonate.

(7) Solutions of the carbonates of magnesium are in marked contrast to those of the calcium salts. When the partial pressure of the carbon dioxide in the gas phase is not less than in atmospheric air upward of 50 per cent of the base may be combined as normal carbonate, if the solution is not in contact with the salt in the solid phase; the percentage falls below 35 per cent when in contact with the solid normal carbonate. Both normal carbonate and hydrogen carbonate are to be considered in dealing with solutions of the magnesium salts.

(8) The formation of soluble normal carbonates or "black alkali" would take place to a greater extent in the presence of magnesium carbonate than in the presence of calcium carbonate alone in the soil.

(9) The observations and conclusions presented in this paper are in thorough accord with the experiences of the field parties of this Division

SOLUBILITY OF GYPSUM IN AQUEOUS SOLUTIONS OF SODIUM CHLORIDE.

By FRANK K. CAMERON.

INTRODUCTION.

The effect of one electrolyte in determining the solubility of another in water solutions has received considerable attention from investigators within the past few years. This work has been directed mainly to a verification of theories deduced from applications of the mass law to electrolytic dissociation and quite satisfactory results have been obtained for very dilute solutions.

Excepting the early classical researches of Kopp,[1] Karsten,[2] Rüdorff,[3] and Engel,[4] but little satisfactory work is to be found described in the literature on this subject when concentrations of any magnitude were involved or when the work was carried on through any great range of concentration. Moreover, the cases thus studied have been carefully selected so as to take advantage of some peculiar characteristic of one or more of the components in the system under consideration and thus simplify the theoretical formulation of the factors involved. Such cases as one meets most frequently in every-day practice—two strong electrolytes in water, for example—have received but scant attention. The reason for this is that such cases *a priori* could not be expected to give satisfactory results, so far as the theories under examination were concerned, it being a well-established fact that for such electrolytes the dissociation does not take place in accordance with the *mass law*, as we now formulate it. This point will be referred to again.

For a correct understanding of the "alkali" problem of the arid regions, such a problem as occurs in many of our Western States, this mutual influence of salts or electrolytes in solution is of very great importance. Qualitatively we already know something in this connection, but quantitative data have been almost entirely wanting up to the present.[1]

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[1] Ann., **34**, 260 (1840).

[2] Abhandl. der Berlin Akad. (1841).

[3] Pogg. Ann., **148**, 456, 555 (1873). Wied. Ann., **25**, 626 (1885).

[4] Compt. rend., **102**, 113 (1886).

We have to do here with solutions often far from dilute, and we have no consistent theory to guide us; furthermore, the particular salts involved in the "alkali" problem have not commended themselves to investigators.

It is seldom that we have to deal with but one pair of electrolytes and their metathetical products in the study of an "alkali" problem, but in the absence of any available data it was deemed wise to take a case of this kind for a preliminary study. Accordingly, from time to time, as attention to other work of the laboratory permitted, the solubility curves for several pairs of electrolytes have been followed quantitatively. Some results are here recorded for the system: Water, calcium sulphate, sodium chloride, and their reaction products.

DESCRIPTION OF EXPERIMENTS.

Solutions of sodium chloride of various concentrations were prepared. The sodium chloride used was chemically pure material obtained from Eimer and Amend and tested by analyzing for chlorine with very satisfactory results. Into these sodium chloride solutions an excess of calcium sulphate in the form of finely divided gypsum ($CaSO_4.2H_2O$) was introduced, and the solutions then allowed to stand, with frequent shakings, from one to fourteen days, according to the temperature at which the work was being done, in order that equilibrium might be reached. The gypsum used in the experiments described in this paper was from two sources. One sample was a very finely powdered gypsum obtained from Hot Springs, Fall River County, S. Dak., an analysis of which gave very satisfactory results for the formula $CaSO_4.2H_2O$. The material was powdered so finely that it displayed a decided tendency to "cake," and when used the solutions had to be shaken frequently. This "caking" did not resemble the setting of plaster of paris, but the substance behaved more like a plastic clay. The other gypsum sample was obtained by pulverizing in an agate mortar some very fine crystals of gypsum kindly furnished by Mr. Wirt Tassin, of the United States National Museum. It may be said at once that curves were plotted from data obtained with both these materials and with calcium sulphate obtained by precipitation from mixing solutions of calcium chloride and sodium sulphate, all of which agreed most satisfactorily. The material first described possessed one advantage in that its very finely divided condition enabled it to go into solution more rapidly and greatly shortened the time required to obtain final equilibrium in the system.

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[1] For a review of the earlier work see W. W. J. Nicol (Phil. Mag., **31**, 369 (1891) and J. E. Trevor (Phil. Mag., **32**, 75 (1891). More recent investigations of interest in this connection are the Solubility of calcium bicarbonate in sodium chloride solutions, Treadwell and Reuter (Zeit. für anorg. Chem., **17**, 192 (1898); Solubility of gypsum in solutions of hydrochloric acid and calcium chloride, Lunge (Jour. Soc. Chem. Ind., **4**, 31 (1885); Solubility of gypsum in solutions of ammonium chloride, magnesium chloride, and calcium chloride, Tilden and Shenstone (Proc. Roy. Soc., **38**, 335 (1885); Solubility of calcium sulphate in several acids, Ostwald and Banthisch (Jour. für prak. Chem. [2], **29**, 52 (1884).

Preliminary experiments indicated the advisability of using rather large volumes of solution. About 300 cubic centimeters were found to be a very convenient amount. In the experiments at higher temperatures the portions of solutions required for analysis were drawn off with a pipette as quickly as possible, care being taken to avoid drawing off any solid gypsum. In some cases considerable difficulty was experienced in this respect, but it is not believed that any of the results here presented are open to criticism on this account. When working at the lower temperatures, a 100 cubic centimeter portion was filtered through a "Schleicher und Schüll" folded filter, discarding the first runnings. This 100 cubic centimeter portion was then diluted to 500 cubic centimeters, and aliquot parts taken for the analytical determinations. The chlorine was determined by titrating with a carefully standardized silver nitrate (N/10 $AgNO_3$) solution, using potassium chromate as indicator. The sulphates were estimated gravimetrically as barium sulphate, in the usual manner. In some cases the calcium was also determined, but as nothing especial was thus gained this last procedure did not seem to be advisable.

For a constant temperature bath a large washtub filled with water was used. With such a large volume of water the temperature changed quite slowly, and by passing in a stream of water or steam, as the case might be, no serious difficulty was experienced in keeping a temperature constant within a degree or a degree and a half Celsius. To attempt greater accuracy in this direction was not justifiable in view of the results obtained, and the advantage derived in being able to work with large volumes of solution in a bath of this size far outweighed any disadvantage arising from a variation in the temperature of the magnitude described.

DETERMINATIONS MADE AT 15° C.

The first series of determinations obtained were made at 15° C. They are given in Table VIII, in which the first column contains the amounts of sodium chloride in the solution, assuming all the sodium and chlorine to be thus combined, and the second column containing the corresponding amounts of calcium sulphate found to be soluble. A much more complete set of determinations was then made at 23°.

Table VIII.—*Solubility of calcium sulphate in aqueous solutions of sodium chloride at 15° C.*

Grams NaCl per liter.	Grams $CaSO_4$ per liter.
0.6	2.3
1.1	2.5
5.1	3.1
10.6	3.7
31.1	4.8
51.4	5.6
139.9	7.4

Table IX.—*Solubility of calcium sulphate in aqueous solutions of sodium chloride at 23° C.*

Grams NaCl per liter.	Reacting weights NaCl per liter.	Grams $CaSO_4$ per liter.	Reacting weights $CaSO_4$ per liter.	Grams gypsum per liter.
0.99	0.0171	2.37	0.0176	2.99
4.95	.0852	3.02	.0223	3.82
10.40	.1790	3.54	.0262	4.48
30.19	.5200	4.97	.0368	6.31
49.17	.8471	5.94	.0439	7.51
75.58	1.3018	6.74	.0499	8.53
129.50	2.2314	7.50	.0555	9.42
197.20	3.3968	7.25	.0536	9.17
229.70	3.9568	7.03	.0520	8.88
306.40	5.2785	5.68	.0420	7.19
[a] 315.55	[a] 5.4348	[a] 5.37	[a] .0397	[a] 6.79

[a] The solution in this case was in contact with both gypsum and sodium chloride in the solid phase.

DETERMINATIONS MADE AT 23° C.

The data given in Table IX are the results of experiments made with more than ordinary care. The calcium sulphate used was prepared by pulverizing selected gypsum crystals. Other series made at this temperature with calcium sulphate from various sources showed most satisfactory agreements, and it is not deemed worth while to present them here. The results given in this table are presented graphically in fig. 3. The ordinates represent grams gypsum per liter of solution, and the abscissas grams sodium chloride per 100 cubic centimeters. For convenience in reference, the corresponding values in reacting weights and in anhydrous calcium sulphate are also given in the table. No advantage is evident in charting the curve in terms of these latter quantities, it being merely displaced somewhat thereby without changing its general nature, and the form in which it is presented promises greater usefulness to the work of this Division.

By referring to fig. 3 it will be observed that the solubility of the calcium sulphate or gypsum reaches a maximum in solutions containing about 135–140 grams of sodium chloride per liter, upward of 7.5 grams calcium sulphate—equivalent to 9.3 grams gypsum—being dissolved at this concentration, against approximately 2 grams calcium sulphate, equivalent to 2.7 grams gypsum soluble in pure water.

In view of the generally accepted ideas on the mutual effect of electrolytes in solution, the existence of this maximum solubility point was entirely unexpected and surprising.[1] The data given are calculated with reference to a constant volume of solution. It seemed possible that the relatively large amounts of salts present in the more concentrated solutions had replaced so much of the volume of the solvent in this constant volume of solution that the existence of this maximum solubility was only apparent and not real. Experiments to test this point will be described presently.

It was deemed advisable to determine experimentally whether or not the composition of the solid phase, containing both sodium chloride and gypsum, would affect the composition of the solution in contact with it. Therefore two mixtures, containing, respectively, 45 grams of sodium chloride with 1 gram of gypsum and 45 grams of sodium chloride with 10 grams of gypsum, were each brought into contact with 100 c. c. of distilled water. The mixtures were shaken continuously for four days, then placed in the constant-temperature bath and allowed to settle. An analysis of the supernatant solutions gave identical results for both cases. As there was no reason *a priori* to expect a different result with this pair of electrolytes no further experiments on this point were deemed necessary.

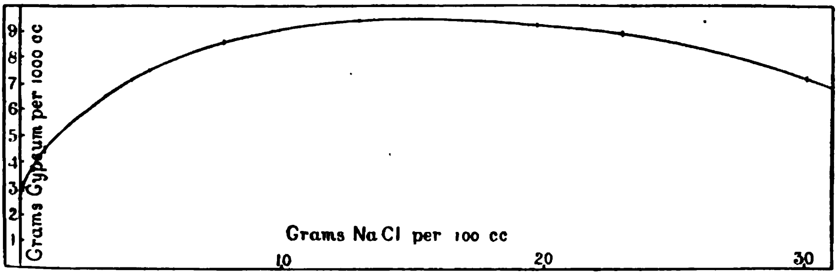

Fig. 3.—Diagram showing the solubility curve for gypsum in solutions of sodium chloride.

DETERMINATIONS MADE AT HIGHER TEMPERATURES.

In Table X the data obtained at higher temperatures are given. The results are not presented in graphic form because the curves would lie so close together, when plotted on any convenient scale, as to fail to bring out more clearly than the tables do any points especially worth noting.

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[1] It had been observed, however, by Tilden and Shenstone, Proc. Roy. Soc., 38, 335 (1885).

Table X.—*Solubility of calcium sulphate in aqueous solutions of sodium chloride at various temperatures.*

30° C.		70° C.	
Grams NaCl per liter.	Grams $CaSO_4$ per liter.	Grams NaCl per liter.	Grams $CaSO_4$ per liter.
0.5	2.5	0.5	2.2
10.3	3.6	10.0	3.4
30.3	5.0	29.6	4.9
47.3	6.1	48.8	5.8
73.4	6.9	132.7	7.4
126.9	7.3	195.0	7.6
192.4	7.7	....	....

52° C.		82° C.	
Grams NaCl per liter.	Grams $CaSO_4$ per liter.	Grams NaCl per liter.	Grams $CaSO_4$ per liter.
0.5	2.3	0.0	2.07
1.1	2.4	1.0	2.18
5.0	2.9	5.0	2.65
10.1	3.5	10.1	3.30
29.6	5.0	29.5	4.68
48.3	5.8	48.8	5.54
75.7	6.6	74.9	6.23
131.6	7.1	128.7	7.00
195.9	7.4	195.1	7.51

By referring to the tables it will be observed that the curve for 30° C. would lie above that for 23° for the most part, but the curves for 50° and the higher temperatures, respectively, would fall lower and lower on the chart. At first sight this might be attributed to the fact that gypsum shows a maximum solubility in pure water at about 37.5° C., as may be seen by referring to fig. 4, plotted from Marignac's results.[1] But that this fact alone is not sufficient to account for the results noted seems probable when it is observed that the solubility of the gypsum in the sodium chloride solutions, even at 80°, may be increased to nearly 3.5 times its solubility in pure water, whereas the solubility of the calcium sulphate in pure water at 37.5°, the maximum point, is about 1.119 times its solubility at 0°, and about 1.243 times its solubility at 99°, as calculated from Marignac's data. That a causal relation exists between the facts observed is to be expected, but what it may be is not obvious at present.

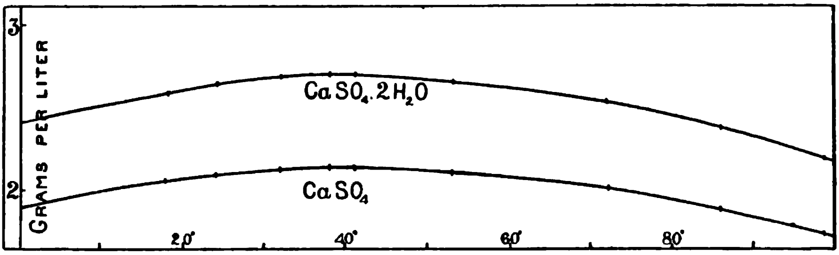

Fig. 4.—Diagram showing the solubility curves for calcium sulphate at various temperatures. Plotted on the basis of gypsum and the anhydrous salt.

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[1] Ann. Chim. et Phys. (5) 1, 274 (1874).

As far as was observed, the curves determined at temperatures above 30° C. were assymptotic, and did not show the existence of "maximum" points. That such points may exist is of course possible, but if so they must lie near the points indicating the extreme solubility of sodium chloride in the system. The labor involved in attempting to locate them did not appear to be justified at the time the curves were determined, and the purposes for which this investigation was undertaken has not since indicated the desirability of a more exhaustive examination for them.

DETERMINATIONS MADE AT 26° C.

In this series the determinations were made on solutions of the volume of a small pycnometer or specific gravity bottle, and in each case the actual weight of the solutions was determined. Having determined the weights of the salts present, the weights of water actually present as solvent were then calculated by subtracting the weights of the salts present from the total weights of the solutions.

The volume of the pycnometer at 26° was carefully determined by boiling it for some time in distilled water, cooling to 26°, weighing it filled, carefully drying, and weighing it empty. The data obtained follows:

	Grams.
Weight of pycnometer filled	**135.5364**
Weight of pycnometer empty	**35.7956**
Weight of water	**99.7408**

The density of water at 26° being taken as 0.99687,[1] the volume of the pycnometer was 100.05 cubic centimeters; therefore no attempt was made to correct the data obtained to the basis of 100 cubic centimeters, the variations being very probably within the limits of error of the methods used.

Table XI contains data obtained from experiments made at 26° C. A comparison of the data in Table XI with that in Table IX shows a very satisfactory agreement between the two series of determinations made at 23° and 26°, respectively.

Table XI.—*Solubility of calcium sulphate in aqueous solutions of sodium chloride at 26° C.*

Grams solution per 100 c. c.	Grams water per 100 c. c.	Grams NaCl per 100 c. c.	Grams $CaSO_4$ per 100 c. c.
99.9848	99.7727	0.0000	0.2121
106.4441	96.6631	9.1154	.6656
109.8113	94.6945	14.3989	.7179
110.1215	94.5708	14.8343	.7164
111.9622	93.6001	17.6502	.7119
114.8826	91.3276	22.8756	.6794
117.0720	90.0049	26.4173	.6498
120.3439	87.7233	32.0491	.5715

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[1] Smithsonian Physical Tables, Gray, p. 94 (1896).

NATURE OF THE CURVE REFERRED TO A CONSTANT WEIGHT OF SOLVENT.

From the results given in Table XI were calculated those given in Table XII; that is to say, the amounts of calcium sulphate in a solution saturated with respect to it and the corresponding amounts of sodium chloride when the solution contains exactly 100 grams of water and irrespective of whatever volume the solution might have.

Table XII.—*Total NaCl and $CaSO_4$ in water at 26° C.*

NaCl per 100 grams water.	$CaSO_4$ per 100 grams water.
0.0000	0.2126
9.4307	.6886
15.2056	.7581
15.6859	.7575
18.8570	.7605
25.0478	.7439
29.3509	.7219
36.5343	·6515

From this table it will be seen that a well-marked maximum solubility point does exist. This point corresponds in round numbers to 0.76 gram of calcium sulphate and 15.3 grams sodium chloride in 100 grams of water. The sixth determination shows an apparent discrepancy, but this is probably due to an inaccurate weighing of the solution, since the data of Table XI agree so well with the very carefully established data in Table IX.

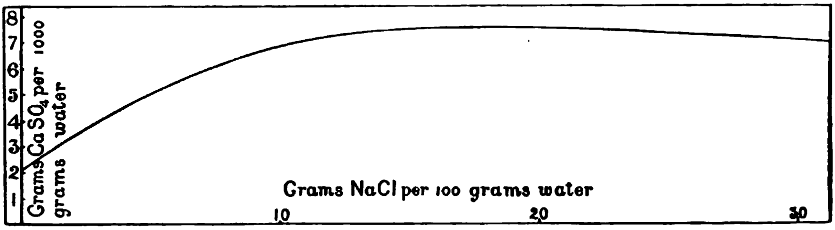

Fig. 5.—Diagram showing the solubility curve for calcium sulphate in solutions of sodium chloride. Results given in terms of grams present in a constant weight of water.

The data given in Table XII are represented graphically in fig. 5, from which the general nature of these solubility changes is readily apparent.

Tilden and Shenstone[1] obtained similar results for this pair of electrolytes working at 20° C. The curve obtained by them follows very closely the curve given here, but lies somewhat above. Nevertheless, it is believed that the results given here are the more reliable, as they have been repeated several times and with great care. The maximum point on Tilden and Shenstone's curve would be displaced somewhat further to the right than in the curve here given. It seems possible that the discrepancies between the two curves at highest concentration might disappear if they could be compared on exactly the same basis; but the statement of the results of the authors quoted is somewhat vague on this point, and it is not quite certain on what basis their results were computed.

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[1] Proc. Roy. Soc., 38, 335 (1885).

SOLUBILITY CHANGES FOR GYPSUM WITH VARYING TEMPERATURE.

Above 37° to 38° the solubility of gypsum in pure water decreases with rising temperature, and, as will be seen from Marignac's[1] results, given in Table XIII and plotted in fig. 5, at a point a little above 80° the solubility becomes less than at any lower temperature.

TABLE XIII.—*Solubility of gypsum in water at various temperatures.*

Temperature.	Calculated for gypsum.		Calculated for calcium sulphate.	
	Parts water required to dissolve one part $CaSO_4.2H_2O$.	Grams $CaSO_4.2H_2O$ dissolved by a liter of water.	Parts water required to dissolve one part $CaSO_4$.	Grams $CaSO_4$ dissolved by a liter of water.
° 0	415	2.41	525	1.90
18	386	2.59	488	2.05
24	378	2.65	479	2.09
32	371	2.70	470	2.13
38	368	2.72	466	2.15
41	370	2.70	468	2.14
53	375	2.66	474	2.11
72	391	2.56	496	2.02
86	417	2.40	528	1.89
99	451	2.22	571	1.75

From the data presented above it would appear that the solubility of gypsum follows the same general law when sodium chloride is present, up to a concentration for this latter salt of about 135–140 grams per liter of solution. The figures of Tilden and Shenstone[2] for the solubility of gypsum in a 25 per cent solution of ammonia chloride indicate that while a maximum solubility point is reached with rising temperature it lies at or above 60° C. It seems very desirable, however, that their results for this particular case should be repeated before much weight be given them. On the other hand, they showed that when the gypsum was dissolved in solutions of calcium chloride, in which case the two substances furnish a common ion, that the solubility steadily increased without the appearance of any maximum solubility point, at least as far as 94° C.

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[1] See also Goldammer, Chemisch. Centralb., p. 708 (1888), whose results indicate a maximum solubility for gypsum in water at about 37.5° C., while Poggiale, Ann. de Chim. et Phys. (3), 8, 469 (1843), found it to be at 35° C.

[2] Proc. Roy. Soc. 38, 335 (1885).

CHANGE IN DENSITY OF THE SOLVENT.

In the course of experiments for the solubility curve at 26° C. the fact was brought out that calcium sulphate dissolved in water caused a contraction of the solvent, as will be seen from the following figures:

	Grams.
Weight of pycnometer filled with water at 26° C	135.5167
Weight of pycnometer empty	35.7965
Weight of water	99.7202
Weight of pycnometer filled with solution of calcium sulphate saturated at 26° C	135.7813
	35.7965
Weight of solution	99.9848
Weight of calcium sulphate	.2121
Weight of water as solvent	99.7727
Weight of water alone	99.7202
	.0525

In other words, although a portion of the volume of the water was displaced by the calcium sulphate in solution, the water as solvent weighed 0.0525 grams more. Therefore there must have been an actual condensation of the solvent. The fact that such a condensation does take place as a rule when salts are dissolved in water has been known for some time, and Nernst[1] has suggested that this fact may possibly be connected with the phenomena of electrolytic dissociation, but as yet the nature of this connection has not been ascertained. The experiment was repeated with results agreeing fairly well with those given, but as the temperature was not noted it is not considered worth while to present them here. The water used in the experiments just described was not boiled. But if we take the results given on page 31 we have the following data for 26° C.:

	Grams.
Weight of pycnometer with water	135.5364
Weight of pycnometer empty	35.7956
Weight of water (boiled)	99.7408
Weight of water as solvent	99.7727
	.0319

From these figures it would appear that the condensation was somewhat less than the first figures indicated, and that it would be worth while to redetermine the condensation by boiling both the pure water and the solution. This was done, but owing to a misunderstanding the determinations were made at 31° C. instead of 26° C. The weight of calcium sulphate taken was not determined directly, but was obtained by interpolation on the curve plotted from Marignac's results.

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[1] Theoretical Chemistry (translated by Palmer), p. 332, 1895.

	Grams.
Weight of pycnometer filled with water	135.4241
Weight of pycnometer empty	35.7965
Weight of water (boiled)	99.6276
Weight of pycnometer filled with solution	135.7844
Weight of pycnometer empty	35.7965
Weight of solution (boiled)	99.9879
Weight of calcium sulphate	.2130
Weight of water as solvent	99.7249
Weight of water (boiled)	99.6276
	.0973

From the figures just presented the density of the calcium sulphate solution will be 1.0031 at 31° when compared with water at the same temperature. Making the assumption that the air dissolved in both solution and in water alone was the same, the density at 26° would be 1.0026. It is given as 1.0022 at 15° by Stolba.[1] It would be interesting to compare these values by the methods of Valson[2] and Bender.[3] But a saturated solution of calcium sulphate is only about a hundred and fiftieth normal (N/150), and in consequence we have not been able to find any data already determined and suited to this purpose.

COMPOSITION OF THE HYDRATE OF CALCIUM SULPHATE IN CONTACT WITH SOLUTIONS.

It has frequently been necessary in the work of the laboratory to heat solutions containing calcium and sulphuric acid salts to temperatures higher than 80°, and the frequent precipitation of calcium sulphate under these circumstances had raised the suspicion that possibly some other hydrate of calcium sulphate than the dihydrate was formed at this temperature.

The suspicion was strengthened by the frequently observed fact that when solutions containing calcium sulphate and other salts were evaporated to dryness the residue apparently would not redissolve in the amount of water originally present. A microscopic investigation of this apparently insoluble residue left but little doubt that it was composed entirely of small gypsum crystals. These might of course have resulted from another hydrate on standing at a temperature at which the dihydrate was the stable form; but this would have assumed a high speed of transformation, as in some cases the microscopic examination was made as soon as possible after removing the material from the steam bath.

Hoppe-Seyler observed that gypsum lost water when heated to

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[1] Jour. prakt. Chem., **97**, 503 (1866).

[2] Compt. rend., **73**, 441 (1871); **77**, 806 (1873).

[3] Wied. Ann., **20**, 560 (1883).

120°–130° in contact with saturated solutions of sodium chloride or calcium chloride. Rose[1] observed the same phenomenon when the gypsum was heated in contact with a solution of sodium sulphate, although he doubted if it took place with a solution of sodium chloride.

Three 100 cubic centimeter measuring flasks were filled with solutions containing considerable amounts of sodium chloride, and saturated with respect to gypsum. The contents of the flasks were evaporated to dryness in platinum dishes on the steam bath; the residues were then washed back into the 100 cubic centimeter measuring flasks which were filled to mark, stoppered, and set aside. From time to time these flasks were vigorously shaken. In one case the solution had been frequently stirred while evaporating on the water bath, and the gypsum crystals which separated were very small. In this case about eight days were required for re-solution to be complete; in the two other cases about sixteen and twenty-two days, respectively, were required, but in all three cases the re-solution was complete in the course of time. It thus appeared that the formation of a different hydrate above 80° was a gratuitous assumption; the more probable explanation of the facts observed is that the rate of solution of gypsum crystals is very slow, even when large amounts of sodium chloride are present.[2]

Since the experiments just described were made, a paper by van't Hoff and Armstrong[3] has been published, from which it appears that the transition point for the two solid hydrates, $CaSO_4.2H_2O$ and $CaSO_4.\frac{1}{2}H_2O$, is 101.45° when in contact with a solution of sodium chloride of considerable concentration. With certain other substances, however, this transition temperature is much lower. For example, these investigators found it convenient to prepare the hydrate, $CaSO_4.\frac{1}{2}H_2O$, by keeping gypsum, $CaSO_4.2H_2O$, in contact with concentrated nitric acid at 40° for some time. It might be supposed that this transition takes place at this lower temperature on account of the strong affinity of the nitric acid for water. The results of Vater[4] rather tend to confirm this view. He found that from saturated solutions of sodium chloride at all ordinary temperatures calcium sulphate separated in the form of gypsum, $CaSO_4.2H_2O$. This hydrate also separated from solutions containing as much as 3 per cent of magnesium chloride; but from saturated solutions of magnesium chloride gypsum, $CaSO_4.2H_2O$, separated below 40°, and the hydrate, $CaSO_4.\frac{1}{2}H_2O$, above 40°. Magnesium chloride has a strong tendency to crystallize under such conditions as the hexahydrate; that is to say, shows a strong affinity for water. From these facts it would seem that gypsum is not a stable hydrate above 40° in the presence of other substances which are strongly deliquescent, but that in the presence of a neutral substance like sodium chloride, which does not form a hydrate either in the solid or liquid phase, it is stable up to a temperature of 101.45° C.

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[1] Pogg. Ann., 93, 606.

[2] Since this work was done, Ostwald, Zeit. für physk. Chem., 34, 495 (1900) has suggested that a substance may have different solubilities, depending upon the size of the particles of the solid in contact with its solution. It is believed, however, that it has been amply demonstrated that in these gypsum solutions that final equilibrium conditions will be the same, and it is the rate of solution which has been the disturbing factor hitherto in their study.

[3] Sitzungsber. K. Preuss. Akad. Wiss., 28, 559–576 (1900). See also Zunino, Gazz. Chim. Ital., 30, I, 333 (1900).

[4] Sitzungsber. K. Preuss. Akad. Wiss., 28, 269–294 (1900).

It will be recalled that the maximum solubility of calcium sulphate in water is at about 40° C. (more exactly, 37.5°), and the idea suggests itself that perhaps this is the true transition point; the supposed solubility curve for gypsum from 0° to 100° being in reality two solubility curves—one for the dihydrate and the other for the hemihydrate—intersecting at 37.5°, both being so flat they run into each other as though but one curve. But this view is negatived by the fact that the transition does not take place in contact with sodium chloride solution until a temperature of 101.45°; and, as will presently be shown, it does not apparently take place at all in a perfectly indifferent medium at any temperature below that sufficient to drive out all the water from the substance. Further, the transition of gypsum to the hemihydrate when in contact with pure water above 40° has not yet been observed.

The statements of van't Hoff and Armstrong and of Vater were confirmed by experiments in which some cleavage pieces of a very fine gypsum crystal were put into the various solutions at the temperatures stated. When transformation to the hemihydrate, $CaSO_4.\frac{1}{2}H_2O$, took place, the surface of the gypsum soon became very white and opaque and the surface roughened, but after standing some time, if dropped into water, the opacity disappeared and the substance gradually became perfectly clear and transparent again. This transformation from one hydrate to another could be very beautifully and readily followed when the cleavage piece was in contact with sodium chloride solutions, for the changes were then fairly rapid. It seemed worth while to see if the transition temperature would be the same when the hydrate was in contact with other presumably neutral substances. Therefore a clear transparent cleavage piece of gypsum crystal was dropped into a test tube containing melted paraffin and the temperature gradually raised by immersing in a water bath to which sodium chloride was added from time to time to raise the boiling temperature. No transition to the hemihydrate appeared when the temperature reached 101.50° C. The temperature was then raised to 104° and kept constant for about six hours. No formation of the hemihydrate could be observed, and the temperature was then gradually raised to 115° without any change in the gypsum being apparent. The test tube containing the paraffin and gypsum was then withdrawn from the bath and quickly heated to about 145° C. over a bunsen lamp. At this temperature the crystal rapidly lost water, crumbled to pieces, and the residue appeared to be the anhydrous salt, $CaSO_4$, although a more thorough analytical examination would be desirable before making this statement positively. From these facts it is apparent that the equilibrium between the hydrates of calcium sulphate needs further study. But the work was stopped at this point, as further investigation in this direction was scarcely pertinent to the subject of this paper.

RATE OF SOLUTION OF GYPSUM.

In order to get some idea as to how long it would be necessary to allow a solution of sodium chloride to stand in contact with gypsum in order to become saturated with respect to the latter, a large quantity of a solution containing 79.08 grams sodium chloride per liter was prepared. To this solution was added about a gram and a half of gypsum, prepared by pulverizing some selected crystals in an agate mortar. The whole was shaken vigorously for a few minutes. From time to time measured quantities were filtered off, and the amount of calcium sulphate dissolved was estimated by precipitation of the sulphate as barium sulphate. After each filtration the solution with the suspended gypsum was vigorously shaken and set aside until required for the next filtration. The data obtained are given in the following table, the first time reading indicating when the powdered gypsum was added to the sodium chloride solution:

Table XIV.—*Rate of solution of gypsum in solution of sodium chloride.*

Time.	$CaSO_4$ per liter dissolved.
	Grams.
10.00 a. m	0.00
10.17 a. m	5.19
10.53 a. m	5.51
11.17 a. m	5.76
11.48 a. m	6.02
1.04 p. m	6.04

At 9.30 a. m. the following forenoon the amount of gypsum dissolved had not sensibly increased, and it was not until nearly three days after the beginning of the experiment that the solution could fairly be considered as saturated, containing 7.45 grams of calcium sulphate per liter. Unfortunately, no attempt was made to keep the temperature of the solution constant, nor were the temperatures recorded during this experiment. As a matter of fact, the temperature of the room became quite low during the nights, and this probably checked somewhat the rate of solution.

The subject is one of great importance in analytical operations. A great deal of trouble has been met in concentrating or evaporating to dryness "alkali" waters containing sulphates and lime salts and then attempting to redissolve the residue for purposes of analysis. It is frequently desirable for certain work in this Division to prepare artificially, aqueous solutions of salt mixtures. These mixtures are based on the results of chemical analyses of natural water and solutions of soil components, and often these analyses, expressed in the conventional way, show very considerable amounts of calcium sulphate. It has frequently happened that these mixtures could not be made to dissolve in a reasonable time, and the undissolved residue has generally proved to be calcium sulphate when examined chemically. This has sometimes resulted in grave doubt being thrown upon the analyses, besides introducing other annoying features. From what has just been said, however, a way of at least mitigating the difficulty suggests itself; that is, to recalculate the analyses and components of the salt mixture in such a way that the calcium ions and sulphions may each be introduced in the form of more soluble salts. Unfortunately the difficulty can not always be fully met, even when the components are dissolved separately and the solutions brought together, for local supersaturation sometimes causes a separation of fine gypsum crystals which redissolve but very slowly. Nevertheless, this procedure is advised wherever the conditions of the work will permit.

SOLUBILITY OF GYPSUM IN PURE WATER.

The solubility of calcium sulphate in pure water has been frequently determined, but the published results are very conflicting. To account for the discrepancies most astonishing statements as to the supersaturation and under saturation, etc., are recorded. The real cause of the difficulty seems to have been the very slow rate of solution, the time necessary for the obtaining of final equilibrium between the solid solute and solution being relatively very long. For the sake of a comparison, some of the principal determinations at temperatures near that at which we worked are presented in Table XV.

TABLE XV.—*Solubility of gypsum in pure water.*

Authorities.	Temperature.	Parts water required to dissolve 1 part calcium sulphate.	Parts water required to dissolve 1 part gypsum.
	° C.		
Marignac Ann. Chim. et Phys. (5), 1, 274 (1874).	24	479	378
	18	488	886
Poggiale Ann. Chim. et Phys. (3), 8, 469 (1843).	20	415	....
Church Jahresbuch über die Fortschritte, etc., p. 192 (1867).	21.2	....	419
Cozza Gazzetta Chim. Italiana, p. 135 (1873).	22	538	426
Droeze Ber. deutsch. chem. Gesellschaft, 10, 330 (1877).	20	....	371
	25	....	365
Goldammer Chem. Centralblatt, p. 708 (1888).	22.5	480	....
Kohlrausch and Rose [a] Zeitschrift für phys. Chem., 12, 241 (1893).	18	483	383
From data of this paper	26	469	372

[a] Calculated from the published data. Under the circumstances the agreement with Marignac's results is remarkable.

The first column gives the authority, with reference; the second column, the temperature at which the solubility was determined; the third column, the parts of water required to dissolve one part of calcium sulphate, calculated on the basis of the anhydrous salt; and the fourth column, the corresponding calculation on the basis of the dihydrate.

Droeze seems to have given much attention to this solubility determination and, besides making experimental investigations himself, has given a critical review of the work of his predecessors in this direction. He objects to Poggiale's figures, that they were probably obtained by working with a supersaturated solution. That this could have been possible seems absurd, and it is much more probable that Poggiale did some very bad analytical work, for his results are phenomenally high. Again, Droeze objects to Church's results, that they were obtained from unsaturated solutions. The reasons for this conclusion are vague, but we are inclined to hold the conclusion itself to be correct, for Droeze's results agree fairly well with those of Marignac, Goldammer, and Kohlrausch and Rose, while the figures of Poggiale, Church, and Cozza show wide variations.

The solubility, as determined from the data presented in this paper, is somewhat greater than is indicated by the figures of the majority of the investigators cited, but not quite as great as found by Droeze. No special care was observed in obtaining this determination, for at the time the experiment was made it was regarded only as an incident in the gathering of data for the solubility curve and not as a point under special investigation. Nevertheless, it is believed that the value as given here is approximately correct, for it is not easy to see in what respect the details of the experimental determination could be bettered. There can be little or no doubt that final equilibrium between the solid salt and the solution had been reached. The analytical operations involved were carefully performed and the calculations were based on the actual weights of the solvent, as well as the solute found to be present.

THEORETICAL DISCUSSION.

The effect of one electrolytic upon another in aqueous solution can be accounted for by the electrolytic dissociation theory, at least qualitatively. Attempts have not been wanting to formulate a quantitative expression for the phenomena observed. Nernst[1] and Noyes[2], with his pupils, in particular have attacked the problem with marked success by applying the *mass law* of Guldberg and Waage to the particular types of equilibria between electrolytes and their resulting ions which may be presented.

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[1] Zeits. für phys. chem., **4**, 372 (1889): Theoretical Chemistry (Palmer), p. 406.

[2] Zeits. für phys. chem., **6**, 241 (1890); **9**, 603 (1892); **16**, 125 (1899); **26**, 152 (1898); **27**, 267 (1898); Jour. Am. Chem. Soc., **19**, 930 (1898); **20**, 194, 742, 751 (1898); **21**, 217, 511 (1899).

For the case where a pair of binary electrolytes react with the formation of another pair of binary electrolytes and four ions the theory involves the solutions of nine simultaneous equations containing nine variables. For particular cases eight of these variables are determined by various means, and in consequence there is obtained one equation in one unknown quantity, but it is of a high order and involves a very large number of terms. In all the cases so far studied they were so selected that certain restrictions were imposed, arising from the nature of the particular cases themselves, which greatly facilitated their study. Certain special assumptions could be made by which the algebraic expression of the relation between the quantities involved would be very much simplified.

In the case which is the subject of this paper no such assumptions appear justified. In the first place, the concentrations involved are far from what may fairly be considered dilute. All the substances involved in the metathesis $CaSO_4 + NaCl \rightleftarrows CaCl_2 + Na_2SO_4$ are *strong* electrolytes to which the Ostwald dilution law does not apply—that is to say, to which the mass law is *not* applicable as a statement of the equilibria between the quantities of dissociated ions and undissociated salt through any range of concentrations. The ionization constants, which appear in the equations to which reference has just been made, can not be obtained, therefore, in any way which we can at present see. In the case of the calcium chloride and the sodium sulphate supposed to be in the solution there did not appear to be any practicable way to decide in how far the dissociation would take place as for a di-ionic electrolyte or how far as for a tri-ionic electrolyte, with a consequent modification of the theoretical statements. These considerations have finally caused the abandonment of any attempt to make a comparison between theoretically computed results and those actually found, and, in the present state of our knowledge, the results can be presented only as empirical determinations in the trust that in time they may find use in helping to develop a more comprehensive and satisfactory theory for solutions. An approximate idea of the composition of the solution may be obtained, however, from the following considerations:

Since calcium sulphate in the form of gypsum was always present in the solid phase in contact with the solutions, Nernst's[1] theorem will apply to this case, and it may be assumed that the amount of calcium sulphate dissolved but undissociated will be the same for every point on the curve—that is to say, that no matter what the concentration of the solution may be with respect to sodium chloride, the amount of calcium sulphate *as such* which it will dissolve is always the same.

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[1] Theoretical Chemistry, p. 446. See also Report 64, Division of Soils, p. 148 (1900).

If it be assumed that the mass law holds with reasonable accuracy for the conditions of equilibrium between the undissociated calcium sulphate and its ions, $\overset{+}{\mathrm{Ca}}$ and $\overset{--}{\mathrm{SO}_4}$, it follows further that the number of calcium ions and sulphions is a constant for every concentration of the solution with respect to the sodium chloride. The quantitative measurements for these quantities are readily made from the conductivity of a saturated solution of calcium sulphate in pure water.

In fig. 6 these facts are illustrated graphically. Simply for convenience, the diagram is somewhat distorted. Suppose AO to indicate the solubility of calcium sulphate in pure water; BO to indicate the amount of the salt undissociated; AB to indicate the amount of calcium ions or sulphions present. If then the amount of calcium, for instance, in the solution be determined for any point C on the curve and indicated by CF, the amount indicated by EF (=BO) will be present in the form of calcium sulphate undissociated; the amount indicated by DE (=AB) will be present in the form of calcium ions; and a necessary consequence is that the amount indicated by CD must be present in the form of calcium chloride undissociated.

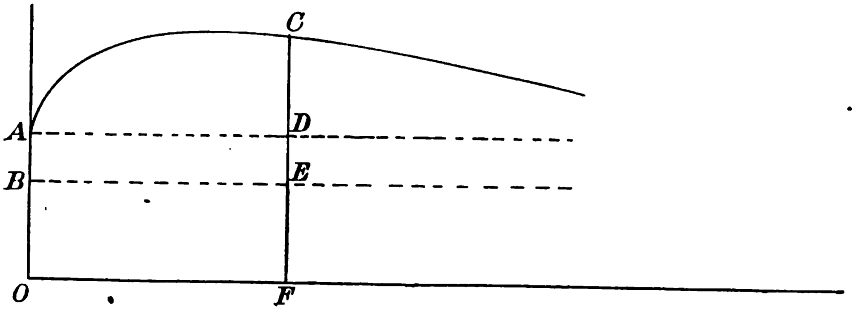

FIG. 6.—Diagram illustrating concentrations of undissociated salts and corresponding ions in solutions of salt mixtures.

In a strictly analogous way the amount of undissociated sodium sulphate present in the solution can be determined. For the complete solution of the problem the amounts of chlorine and sodium as ions and the salt sodium chloride undissociated are required. The difficulties in the way of obtaining these quantities are too great, however, for a practical solution at present.

There does not appear to be any rational explanation for the appearance of the maximum point on the solubility curve. One would naturally expect the solubility of the gypsum to continually increase as the concentration with respect to sodium chloride increases. Noyes[1] has brought forward some evidence to show that as the concentration increases with respect to chlorides of the alkali earth metals, there is a formation of complex ions, for example $\overline{\mathrm{CaCl}_3}$ or $\overline{\mathrm{CaCl}_4}$. The evidence he obtained was rather against the assumption that the sulphates of the alkali metals would dissociate in any but a normal way, as trionic electrolytes; but he worked with quite dilute solutions (up to a tenth molar), and it does not follow that complex ions would not be found in solutions of the concentrations considered in this paper. It is difficult to see how the formation of such complex ions could affect the gypsum in contact with the solution, otherwise than to increase its solubility; and the fact that the solubility actually decreases beyond the maximum point is, as far as it goes, rather to be considered as evidence against the formation of the complex ions. The same thing might be said as to the suggestion that all electrolytes are considerably hydrolized at high concentrations.

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[1] Phys. Rev., 12, 14 (1901), Jour. Am. Chem. Soc. 23, 37 (1901); Zeit. für phys. Chem., 36, 61 (1901).

It seems more probable that the phenomenon is connected with the condensation of the solvent and the effect of such condensation upon the solution tensions of the various electrolytes, and it is earnestly to be desired that some one with time and opportunities undertake an investigation of this subject.

APPLICATION OF RESULTS.

That such data as have been obtained in this investigation will prove of great value in the study of "alkali" problems can scarcely be open to doubt. It is true, as has been pointed out above, that we seldom have to deal with a reaction between but a pair of electrolytes; but it has been clearly brought out in the study of the soils of the valley of the Pecos River, New Mexico, that the more important components of the "alkali" there found are calcium sulphate and sodium chloride. There are large deposits of gypsum scattered throughout this area, and by far the most abundant solute in the waters which come into contact with this gypsum is sodium chloride. The study of the resulting waters, from irrigation, seepage, etc., is largely a study of the equilibrium between these two electrolytes in the solution; to a lesser or greater extent complicated by the presence of other salts, by physical phenomena, etc. Knowing the nature of the water in any particular instance and the soils with which it will come in contact, a much clearer idea of the resulting effects can be prophesied in the light of the data presented in this paper. Much more is yet to be learned, however, before it will be possible to confidently predicate *a priori* much about any particular solution in contact with a soil; for the conditions are exceedingly complex and the many factors entering the problem are very difficult to recognize and follow. For example, it can be readily seen from these solubility curves, how much calcium chloride can be formed in the soils of the Pecos Valley;[1] but it is not so evident why this material should accumulate in a greatly preponderating amount in certain spots, keeping the earth moist in the driest weather and giving it a darker color than the surrounding drier soil to such an extent as to cause such spots to be locally designated as "black alkali." One surface scraping analyzed in this laboratory[1] for its water soluble constituents gave the following results:

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[1] Report 64, U.S. Department of Agriculture. A Soil Survey of Pecos Valley. By Thos. H. Means and F. D. Gardner.

$CaSO_4$	13.39
$CaCl_2$	40.58
$MgCl_2$	18.20
$NaCl$	27.83

from which it appears that at least 40 per cent of the soluble matter must have been calcium chloride. Many similar examples from other areas might be quoted. A sample sent to this laboratory from near Salt Lake City showed even more astonishing amounts of calcium chloride. Unfortunately, the quantitative figures can not be presented, but at least 60 per cent of the total sample must have been calcium chloride.[2] Before such phenomena can be fully understood, much fuller knowledge of the rates of diffusion of the various salts and of the absorption power of the soil grains, etc., must be had. The study of the mutual influence of the electrolytes on their solubility is but the necessary first step in solving the problem presented to us.

The transportation of calcium salts and sulphates through the soil is much more clearly understood in the light of the facts brought out in this paper, and the fact that beyond a certain point gypsum is precipitated from the solution with an increase of sodium chloride in the solution has given a clue as to the formation of gypsum layers in the soil in some of the arid regions. A clearer insight has been obtained as to the formation of alkali and alkali crusts, and this has led to a comprehensive classification of alkali lands, which is described elsewhere.[3]

It is believed, moreover, that the data here presented may find further usefulness in some technical operations, as in the working up of brines, in the preparation of salt, and in the removal of boiler scales, etc. These subjects can only be mentioned, however, in this connection.

For assistance in carrying out the experimental and analytical details of the work described in this paper, the author wishes to record his sincere acknowledgments to Messrs. Frank D. Gardner and Atherton Seidell of this Division.

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[1] Loc. cit., p. 74, soil sample 4058.

[2] This material was leached with distilled water and filtered. The filtrate, after concentrating, was allowed to stand in a desiccator over sulphuric acid, with the result that an astonishingly large amount of the salt calcium chloride (presumably the hexa-hydrate) separated in large, well-characterized crystals. There were also present crystals of sodium chloride and some little stronium chloride, both these latter salts in greatly lesser amounts than the calcium chloride. A complete identification of these products was made by Mr. Wirt Tassin, of the United States National Museum.

[3] Bulletin 17, Division of Soils.

SUMMARY.

Some of the points brought out in the foregoing pages to which attention is especially directed may be stated as follows:

(1) Below 37.5° C. the solubility curves for gypsum in aqueous solutions of sodium chloride show a maximum point. Above this temperature the existence of maximum points is doubtful.

(2) At 23° C. this maximum solubility takes place in a solution containing from 135 to 140 grams sodium chloride per liter.

(3) The solubility of gypsum at 23° in a solution containing 135 grams of sodium chloride per liter is about 9.3 grams per liter. This is equivalent to about 7.5 grams of anhydrous calcium sulphate per liter.

(4) The solubility of gypsum in solutions containing less than 140 grams of sodium chloride per liter is very little affected by change of temperature.

(5) Maximum points in the solubility curve still persist, even if the solubilities be calculated on the basis of the weight of solvent present rather than the volume of the solution.

(6) A condensation of the water as solvent takes place when gypsum and sodium chloride are brought into solution.

(7) The rate of solution of gypsum is very slow, and at ordinary temperatures the time required for equilibrium to be brought about is often great. This fact accounts for the apparent insolubility of gypsum crystals in that volume of solution from which they were originally obtained.

(8) The transition temperature at which the dihydrate and hemihydrate of calcium sulphate are in equilibrium appears to be dependent upon the nature of the substance or substances in the solution with which they are in contact.

(9) At 26° the solubility of gypsum is about 1 part in 372 parts of pure water.

(10) The specific gravity of a saturated solution of gypsum in pure water is 1.0026 at 26° C., and 1.0031 at 31°.

(11) The application of the mass law, as formulated by Guldberg and Waage, to the phenomena of electrolytic dissociation fails to account for the observations here recorded.

(12) The existence of a maximum point on the solubility curve is not accounted for by the hypothesis of the existence of complex ions in the solution. It is probably connected with the condensation of the solvent in aqueous solutions of electrolytes.

(13) The data presented furnishes, in part at least, an explanation of certain phenomena observed in studying alkali soils, and possible applications in technical processes are suggested.

SOLUBILITY OF GYPSUM IN AQUEOUS SOLUTIONS OF CERTAIN ELECTROLYTES.

By FRANK K. CAMERON and ATHERTON SEIDELL.

INTRODUCTION.

The results obtained in the study of the solubility of gypsum in aqueous solutions of sodium chloride were of such a character as to make it appear desirable to obtain data for other solutions of a similar kind. The work was therefore continued and a description of the investigation is here recorded. The choice of the electrolytes was governed mainly by the desire to throw light upon certain problems arising in the study of alkali lands by the field parties of this Division, which problems need not be more particularly described at this point. The solubility of gypsum was therefore determined in solutions of magnesium chloride, calcium chloride, sodium sulphate, and in solutions of sodium chloride when calcium carbonate in the solid phase was also in contact with the solution.

All these determinations were made at temperatures from 23° C. to 26° C. The temperature of the laboratory held quite constantly within these limits and, as slight changes of temperature were found to affect the solubility of gypsum in these solutions but very little, it was not deemed necessary to use a constant temperature bath.

It is desirable for some reasons, both scientific and technical, that determinations should be made at other temperatures, especially above 40° C.; but the exigencies of the public service hardly seemed to warrant them being made at this time.

Instead of gypsum, precipitated calcium sulphate, obtained from Baker and Adamson and labeled C. P., was used in these experiments. It was found by examination of a few solutions that, as was the case in sodium chloride solutions described in the preceding paper, the same results were obtained with gypsum and with precipitated calcium sulphate; but that the solutions came to equilibrium more rapidly when the latter was used. The other salts used in the investigation were chemically pure materials obtained from the same firm.

The general method of procedure was the same in all cases. A series of solutions of various concentrations with respect to the readily soluble salt was prepared, and enough calcium sulphate added to insure an excess of this substance in the solid phase. The solutions were then set aside for periods of from one to six weeks, with occasional vigorous shaking.

The solutions were generally of about 700 c. c. volume and were contained in liter Florence flasks fitted with rubber stoppers, to prevent evaporation of the solvent. When ready for analysis, they were allowed to settle, and appropriate portions of the clear supernatant solutions were drawn off with a pipette, and whenever this procedure seemed advisable they were filtered. The analytical operations were conducted according to the conventional methods and call for no special comment. The amount of calcium sulphate which had dissolved was calculated from the amount of sulphions found in the solution. The results obtained are presented graphically in fig. 7; the ordinates represent grams per liter of calcium sulphate, and the abscissas represent grams per liter of the more soluble salt used.

For some reasons it seemed more advisable to give the results in terms of calcium sulphate found in the solution rather than in amounts of gypsum found to be soluble. These latter can always be readily obtained by multiplying the given results by the factor 1.2647. In fig. 8 the solubility curves are given in terms of the number of reacting weights found in the solution.

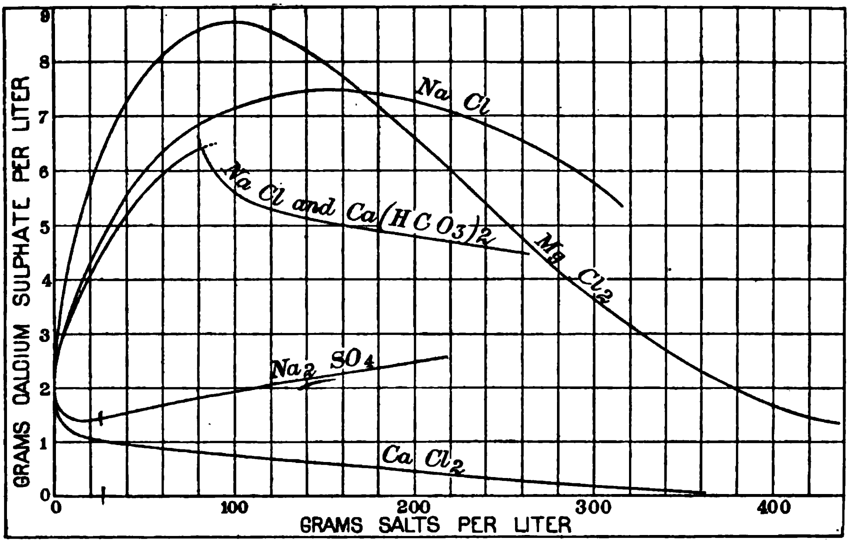

FIG. 7.—Diagram showing solubility curves for calcium sulphate in solution of other salts. Results given in terms of grams per liter.

Although the temperature was not quite the same for these different series of determinations, in all these series it was found that such small differences of temperature as are involved here have such a small influence on the solubility of the calcium sulphate that these curves may fairly be considered as entirely comparable.

SOLUBILITY OF CALCIUM SULPHATE IN MAGNESIUM CHLORIDE SOLUTIONS.

It was found that the curves illustrating this case showed unusually well-marked maximum points. Therefore it was deemed advisable to determine the curve with reference to a constant weight of the solvent water as well as to a constant volume of the solution. The data obtained at 26° C. are given in the accompanying table, which is self-explanatory. The results, referred to a constant volume of solution, are presented graphically in figs. 7 and 8.

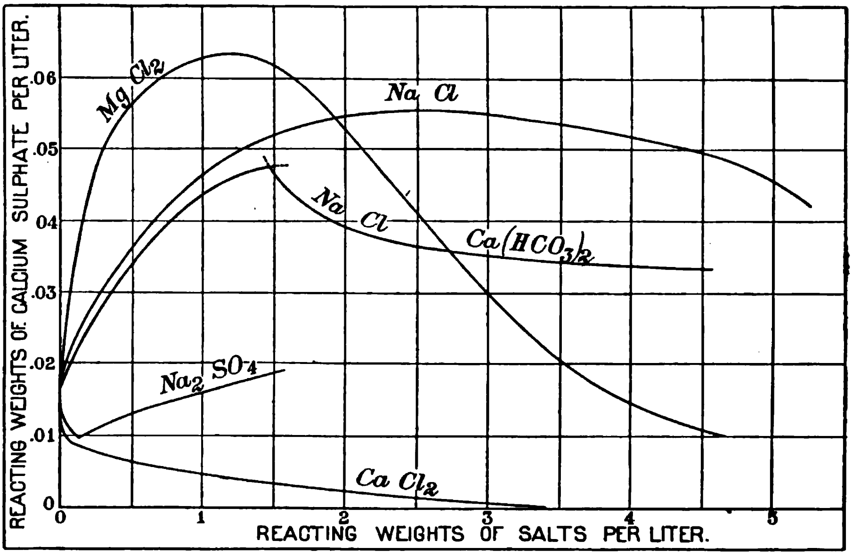

Fig. 8.—Diagram showing the solubility curves for calcium phosphate in solutions of other salts. Results given in terms of reacting weight per liter.

Table XVI.—*Solubility of calcium sulphate in aqueous solutions of magnesium chloride at 26° C.*

H_2O (grams per liter).	$CaSO_4$.		$MgCl_2$.	
	Grams per liter.	R. Wts. per liter.	Grams per liter.	R. Wts. per liter.
997.924	2.082	0.0154	0.000	0.0000
996.520	4.258	.0315	8.501	.0900
994.489	5.692	.0421	19.175	.2030
989.143	7.588	.0561	46.640	.4938
972.218	8.622	.0638	121.381	1.2850
949.950	6.567	.0486	206.985	2.1912
908.678	2.774	.0205	336.986	3.5674
878.588	1.385	.0102	441.128	4.6699

$CaSO_4$.		$MgCl_2$.	
Grams per 1,000 grams of water.	R. Wts. per 1,000 grams of water.	Grams per 1,000 grams of water.	R. Wts. per 1,000 grams of water.
2.086	0.0154	0.000	0.0000
4.273	.0316	8.531	.0903
5.724	.0423	19.860	.2102
7.674	.0568	47.170	.4993
8.867	.0656	124.800	1.3212
6.913	.0511	217.900	2.3068
3.553	.0263	370.900	3.9265
1.577	.0116	502.000	5.3144

By interpolation on the curves it appears that the maximum solubility for calcium sulphate is about 8.8 grams per liter in a solution containing about 105 grams per liter of magnesium chloride. In this solution, therefore, there is more than four times as much calcium sulphate as in a saturated solution of this substance alone. Calculated as gypsum, this maximum solubility is 11.129 grams per liter, or 4.23 times as much as is soluble in pure water. Beyond the maximum point the solubility of the calcium sulphate decreases quite rapidly as the concentration with respect to magnesium chloride increases, this decreasing solubility being much more rapid than in the corresponding curve for the solubility of gypsum in sodium chloride solutions. This decrease in solubility continues until in a solution containing about 370 grams magnesium chloride per liter the solubility of gypsum is the same as in pure water. Therefore, even in the presence of this salt, which does not yield a common ion, the solubility of gypsum is less at high concentrations than in pure water.

The curve plotted from the data obtained on the basis—grams of salt per 1,000 grams of the solvent is of the same general nature as the curve plotted on the basis of a constant volume of solution, and shows about equally well the character of the phenomena involved. The former lies slightly above the latter, and it does not seem worth while to chart it here. Attention is called to it for it also shows, in a most striking way, the real existence of a maximum point on the solubility curve. It would seem that this pair of electrolytes may be particularly well adapted to a further study along the general lines indicated by the investigation here described.

An inspection of a number of analyses of the water-soluble components of soils in arid regions confirms the results indicated above, in that when the percentage of magnesium and chlorides is large there is evidently a large increase in the solubility of the gypsum in the soils. The explanation of such a conclusion could hardly have been drawn from the inspection of the analyses alone, and, in fact, the relatively large amount of calcium stated in these analyses has sometimes caused grave doubts as to their accuracy. Another point of interest in the curves for this pair of electrolytes is the wavy character for the higher concentrations with respect to magnesium chloride. To what this may be due can not be said at present, but it shows that in all probability complex molecular or ionic changes must take place in the solution at these higher concentrations and that the subject is much in need of further investigation.

By referring to fig. 8 it will be observed that the maximum point on the curve for magnesium chloride occurs at about half the concentration that it does on the curve for sodium chloride; that is, at about the same concentration for chlorine in the two cases, since a reacting weight of magnesium chloride contains twice as much chlorine as does a reacting weight of sodium chloride. But the total amount of calcium sulphate is different in the two cases, showing that magnesium and sodium have markedly different properties, at least in degree, under such circumstances.

SOLUBILITY OF CALCIUM SULPHATE IN CALCIUM CHLORIDE SOLUTIONS.

In the preparation of the calcium chloride solutions for this series of experiments it was found that the solutions were more or less turbid, due to undissolved calcium hydrate originally present in the supposed chemically pure calcium chloride used. A few drops of methyl orange solution were therefore added in each case, and then hydrochloric acid, until the indicator showed the solutions to be neutral. The solutions became perfectly clear and free from suspended matter. The calcium sulphate was then introduced and the usual procedure followed.

In this case the two salts will yield a common calcium ion, and in consequence the solubility of the calcium sulphate will be much decreased by the presence of the calcium chloride. This is shown by the accompanying table of results, obtained on a series of experiments made at 25°C. It is even more strikingly brought out by the graphical representation of the results in figs. 7 and 8. The observations on this pair of electrolytes made by Tilden and Shenstone[1] and by Lunge[2] agree in general with the results given here.

TABLE XVII.—*Solubility of calcium sulphate in aqueous solutions of calcium chloride at 25° C.*

$CaSO_4$.		$CaCl_2$.	
Grams per liter.	R. Wts. per liter.	Grams per liter.	R. Wts. per liter.
2.056	0.01521	0.000	0.00000
1.244	.00921	7.489	.06801
1.181	.00874	11.959	.10860
1.096	.00811	25.770	.23401
1.080	.00790	32.045	.29100
1.016	.00752	51.530	.46794
.841	.00622	97.023	.88106
.465	.00344	192.705	1.74996
.203	.00150	280.303	2.54543
.032	.00024	367.850	3.34045

The solubility of the calcium sulphate decreases very rapidly as the concentration with respect to calcium chloride increases, until a concentration of about 20 grams per liter of this latter salt is reached. From this point the solubility of the calcium sulphate decreases more slowly but steadily, until by extrapolation on the curve it would seem that the solution containing 375 grams per liter of calcium chloride would dissolve practically no calcium sulphate.

Just why there should be so marked a change in the solubility of the calcium sulphate in a solution at a concentration of about 2 per cent calcium chloride does not admit of explanation as yet. It is possible that at concentrations above this the calcium chloride may partially dissociate in such a way as to form complex ions containing both calcium and chlorine[1] and thus diminish the proportional effect of calcium as ions in the solution, forcing back the dissociation of the calcium chloride and consequently the retarding effect upon the solubility of the calcium sulphate. It seems probable, however, that the density of the solvent itself may have an important rôle in this connection.

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[1] Proc. Roy. Soc., **38**, 335 (1885).

[2] Jour. Soc. Chem. Ind., **4**, 31 (1885).

THE SOLUBILITY OF CALCIUM SULPHATE IN SODIUM SULPHATE SOLUTIONS.

In this case it is to be expected that the two electrolytes would yield the common sulph-ion, therefore the solubility of the gypsum should decrease as the concentration with respect to sodium sulphate increases. Such was found to be the case up to a concentration of about 17.5 grams per liter of sodium sulphate, when the solubility of the calcium sulphate was about 1.38 grams per liter, or 1.745 grams per liter of gypsum. At this point, as the concentration with respect to sodium sulphate increases, there is a sudden change in the direction of the curve and the solubility of the calcium sulphate steadily increases until, in a liter of solution containing 230 grams of sodium sulphate, there will be dissolved 2.5 grams of calcium sulphate—a quantity markedly larger than will be dissolved by pure water. The data obtained for this pair of electrolytes are given in the following table:

Table XVIII.—*Solubility of calcium sulphate in aqueous solutions of sodium sulphate at 22° C.*

$CaSO_4$.		Na_2SO_4.	
Grams per liter.	R. Wts. per liter.	Grams per liter.	R. Wts. per liter.
2.084	0.0154	0.000	0.0000
1.583	.0117	2.771	.0196
1.433	.0106	13.820	.0979
1.408	.0104	16.380	.1159
1.569	.0116	39.310	.2786
1.841	.0136	77.320	.5480
2.185	.0162	133.000	.9425
2.414	.0178	193.800	1.3734
[a]2.578	[a].0190	[a]222.580	[a]1.5773

[a] Both calcium sulphate and sodium sulphate in the solid phase were in contact with the solution.

Apparently we have to deal with two solubility curves which intersect at the minimum point. Possibly, at concentrations with respect to sodium sulphate greater than that at the minimum point the dissociation of the sodium sulphate takes place in part according to the scheme:

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[1] Noyes, Physical Rev., **12**, 14, (1901); Jour. Am. Chem. Soc., **23**, 37, (1901); Zeit. für phys. Chem., **36**, 61, (1901).

$$Na_2SO_4 \rightleftarrows \overset{+}{Na} + \overline{NaSO_4}$$

rather than entirely as indicated thus:

$$Na_2SO_4 \rightleftarrows \overset{+}{Na} + \overset{+}{Na} + \overline{\overline{SO_4}}$$

If this be so, it is tantamount to introducing a substance into the solution which does not yield a common ion with calcium sulphate, and which therefore may be expected to increase the solubility of the latter. We thus have the sodium sulphate exerting two effects on the solubility of the calcium sulphate, depending on the way in which it dissociates. These two effects are opposite in direction, and in consequence the resulting effect will be dependent on the relative amounts of the dissociation in the two different ways, which is dependent in turn upon the concentration of the solution with respect to the sodium sulphate itself.

From this point of view one would expect the existence in the solution of a double salt, possibly of the composition $Ca(NaSO_4)_2$. Such a salt is probably the mineral glauberite found in nature, and in fact believed to be a common constituent of some alkali soils. Fritzsche[1] describes a hydrated double sulphate ($CaSO_4.Na_2SO_4.2H_2O$) obtained by heating gypsum with a small amount of water and a large excess of Glauber salt ($Na_2SO_4.10H_2O$). The substance was a well characterized one, crystallizing in fine needles, which, on heating, quickly lost the water it contained, yielding the anhydrous double salt. It was expected, therefore, that this salt, or its hydrate, might be obtained by evaporating solutions of sodium sulphate saturated with respect to calcium sulphate. Such solutions were prepared and allowed to evaporate spontaneously at the room temperature. No evidence of the presence of the double salt, however, could be detected in the residue after evaporation of the water. It should be remembered that in those areas where this double calcium sulphate has been observed in nature, the ground temperatures are frequently very high and the equilibrium conditions for the solution may well be very different from those obtaining at 25° C.

An experiment was then made to see if the composition of the solid phase would affect the composition of a solution in contact with both salts in the solid phase. Four vessels were prepared. In each was placed 100 c. c. of water and 40 grams of sodium sulphate and 1, 2, 5, and 10 grams of calcium sulphate, respectively, insuring the presence of both salts in the solid phase. The vessels were then placed in a shaking apparatus and shaken constantly for four days. The contents were allowed to settle and the supernatant solutions quickly decanted upon folded filters. Aliquot portions of the filtrates were analyzed for calcium and sulphates. It was found that the composition of the solid phase apparently did not affect the composition of the solution, practically identical results being obtained in all four analyses. The solution in contact with both salts in the solid phase was found to contain 222.5810 grams per liter of sodium sulphate and 2.5783 grams per liter of calcium sulphate. These results were entirely unlooked for, and can only be explained on the assumption that at the temperature at which the work was done, about 25° C., the solubility of the double salt is greater than the solubility of either Glauber salt ($Na_2SO_4.10H_2O$) or gypsum ($CaSO_4.2H_2O$), and consequently these salts alone will separate from the solution. It is desirable that some one, with time and opportunity for it, should take this matter up and investigate the system throughout a range of temperature. It is a subject of considerable practical importance in several technical operations, as well as in geological and soil studies.

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[1] Jour. für prakt. Chem., 72, 291 (1857).

It follows from these experiments that, considerable amounts of sodium sulphate being in the solution, the solubility of calcium sulphate or gypsum may be relatively great, instead of falling to a very small figure; and the amount of gypsum in contact with the solution in the solid phase will not have any effect in determining the amount that will go into solution at ordinary temperatures, even though sodium sulphate also be present in the solid phase.

SOLUBILITY OF CALCIUM SULPHATE IN AQUEOUS SOLUTIONS OF SODIUM CHLORIDE AND IN THE PRESENCE OF SOLID CALCIUM CARBONATE.

As has been pointed out in another publication of this Division,[1] the characteristic feature of certain areas of alkali lands is the action of sodium chloride in aqueous solution upon gypsum and calcium carbonate simultaneously. It was therefore determined to study the solubility of calcium sulphate in sodium chloride solutions when calcium carbonate in the solid phase was also in contact with the solution. The solubility of this latter salt is dependent upon the partial pressure of the carbon dioxide in the gaseous phase in contact with the solutions. Therefore, air which had been previously washed in dilute sulphuric acid was bubbled through the solutions for fifty-one days, or until they came to equilibrium.[2] The addition of phenolphthalein to the solution did not show the presence of normal carbonates in any of the solutions. The amounts of bicarbonates found, in the equivalents of calcium hydrogen carbonate dissolved, are given in the accompanying table.

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[1] Bulletin No. 17, Division of Soils, 1901.

[2] It is very probable that these solutions had come to final equilibrium within eighteen days, but the passage of air through them was continued to make certain that such a condition had been reached.

Table XIX.—*Solubility of calcium sulphate in aqueous solutions of sodium chloride in contact with solid calcium carbonate.*

$CaSO_4$		$Ca(HCO_3)_2$		NaCl	
Grams per liter.	R. Wts. per liter.	Grams per liter.	R. Wts. per liter.	Grams per liter.	R. Wts. per liter.
1.9298	0.0143	0.0603	0.000375	0.000	0.0000
2.7200	.0201	.0724	.000450	3.628	.0625
3.4460	.0255	.0885	.000550	11.490	.1979
5.1560	.0381	.1006	.000625	39.620	.6824
6.4240	.0475	.0603	.000375	79.520	1.3698
5.2720	.0390	.0563	.000350	121.900	2.0995
4.7860	.0354	.0482	.000300	193.800	3.3379
4.4620	.0330	.0402	.000250	267.600	4.6090

The variation in the solubility of the calcium carbonate in the solutions of sodium chloride when gypsum was also present in the solid phase will be discussed in more detail in a following paper. The effect of the presence of the calcium carbonate upon the solubility of the calcium sulphate is most strikingly brought out in the graphic presentation of the results in figs. 7 and 8. From a point representing no sodium chloride in solution up to a concentration for this latter salt of somewhat more than 80 grams per liter, the curve follows very closely the curve representing the solubility of calcium sulphate in the presence of sodium chloride alone. The solubility of calcium sulphate steadily increases with increasing concentration of sodium chloride, but at a somewhat diminishing rate from that which obtains when no calcium carbonate was present. As the amount of sodium chloride increases beyond 80 or 100 grams to the liter, the solubility of the calcium sulphate steadily decreases and apparently follows a new curve, the two curves probably intersecting as charted and not forming a continuous curve with a maximum point, as in the case when there is no calcium carbonate present.

It thus appears that while the solubility of gypsum in solutions of sodium chloride would be but little affected by the presence of calcium carbonate up to 8 or 9 per cent solutions, beyond this point its solubility would be considerably diminished. But in solutions nearly saturated with respect to sodium chloride the gypsum would be about twice as soluble as in pure water, even though calcium carbonate be present.

It is interesting to note that while the solubility of calcium sulphate is only about 2.1 grams per liter in pure water, it reaches a maximum solubility of about 7.5 grams per liter in solution containing 140 grams per liter of sodium chloride. But this solubility would be reduced to about 5 grams per liter if calcium carbonate were present, and in the presence of this latter substance the maximum solubility of calcium sulphate is about 6.35 grams per liter in a solution containing only about 80 to 90 grams per liter of sodium chloride.

SUMMARY.

The data which have been presented in the foregoing pages afford much new information on the solubility of gypsum when this substance is a component of the soil. By reference to fig. 3 it will be seen that up to the tenth normal solution the solubility curves in all cases follow, qualitatively at least, the direction indicated by an application of the mass law to the hypothesis of electrolytic dissociation. This is still true for calcium chloride solutions at high concentrations, but in the other cases here recorded it is not true, and it would have been quite impossible to have predicted the character of these solubility curves *à priori.*

The phenomena which have been described in this paper lend support to the view that ionic complexes are formed in solutions of high concentration. Noyes,[1] in a recent publication, has brought forward evidence to show that such ionic complexes are probable in solutions of the chlorides of the alkaline earths, even at quite high dilutions. The investigations in recent years lend much evidence pro and con to the view that such complexes exist, not only in aqueous solutions, but in other solvents.[2] Of great interest in this connection is the fact brought out by Walden[3] that binary electrolytes in general dissociate much more readily than do ternary or quarternary electrolytes. Since it is to be presumed that ternary electrolytes were present in all the solutions studied in this investigation, it is not so surprising, therefore, that abnormal results were observed at the higher concentrations. It seems most probable that all these facts are dependent upon, or at least causally connected with, the considerable condensation of the solvent which takes place when solutes, especially electrolytes, go into the solution; and that much of interest for the general theory of solutions could be obtained by a systematic investigation from this point of view.

It is obvious that mixtures of as simple composition as those described in this paper are quite rare in the soil solutions, and how far the data here presented will be available in discussing such soil solutions is a pertinent question. It must be said that in all probability no strict application of the figures here given can be made in the study of alkali problems, but nevertheless in a qualitative way they are decidedly helpful. For example, it is probably entirely safe to say that the solubility of gypsum in solutions of soluble chlorides increases up to a concentration of from 10 to 15 per cent, and that beyond this concentration the solubility of the gypsum steadily decreases again. The solubility of gypsum in such solutions is probably but little affected by the presence of soluble sulphates. Even more specific conclusions can be drawn, with a great deal of probability, from the known conditions in any given case, but they can be discussed better elsewhere, when these conditions are more specifically under consideration.

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[1] Phys. Rev. **12**, 14 (1901); Jour. Am. Chem. Soc., **23**, 37 (1901); Zeit. für phys. Chem., **36**, 61 (1901).

[2] See Jones, Am. Chem. Journ., **25**, 232 (1901).

[3] Zeit. anorg. Chem., **25**, 209 (1900).

The facts here presented are of great value in explaining the solution of gypsum, its transportation in the soil, and its precipitation from the soil solution in the presence of large quantities of other soluble salts. This matter of the transportation of gypsum and the formation of gypsum layers at various depths in the soil has been, up to the present time, one of the most puzzling and inexplicable problems connected with the investigation of alkali lands.

The large amounts of gypsum found soluble in the analysis of the water soluble components of alkali soils have often been the cause of much astonishment. In these analyses it is necessary to treat the soil with considerable amounts of water, either by successive leaching or by allowing the soil to stand in contact with an excess of water and drawing off the supernatant solution; and it may well be that in this procedure solutions of the more soluble salts will be found of just the concentrations best suited for dissolving a maximum amount of gypsum. These facts should receive earnest consideration in the study of such analyses and in the forming of conclusions from them, for it is altogether probable that the proportions of calcium and of SO_4, which the analyses indicate, are greater than exist in the soil solutions in the ground itself.

It seems probable, from the results of this investigation, that wherever gypsum occurs in the soil there will be a considerable amount of calcium in the soil solution. This is now known to be a matter of great importance from a physiological point of view, enabling the plants to withstand much larger quantities of the more soluble salts than would otherwise be possible. This Division has been cooperating with the Division of Vegetable Physiology and Pathology in some studies along this line, and the results thus far obtained will shortly be presented in another publication.

Calcium sulphate is much more soluble than calcium carbonate, even when there is a considerable amount of carbon dioxide present, and the solubility of the latter salt is thus increased through the formation of the more soluble hydrogen carbonate. It has therefore seemed probable that it would be better in many cases to use the sulphate for liming soils, because in this way more calcium is brought into the ground solution and its ratio to the other bases dissolved is much increased, and because its *active mass* in the solution is greater and its effect upon other soil components is correspondingly increased. On the other hand, it can not have the effect that either the carbonate or hydrate of lime has in counteracting an excess of carbonic or other organic acids in sour soils or in making them slightly alkaline—a condition which appears to be desirable for certain crops. Furthermore, the carbonate and hydrate have certain well-marked effects on the texture of soils, which are sometimes of as much or more importance than the purely chemical results; consequently it seems desirable that the comparative value of these lime salts, or mixtures of them, on soils of various character should receive more attention than has hitherto been given, both in the laboratory and in actual field practice.

The application of soluble mineral fertilizers to the soils of humid areas unquestionably affects the solubility of mineral components of the soils. Such cases are analogous to the gypsum solution, in that a slightly soluble substance is brought into contact with solutions of much more soluble substances. The idea suggests itself that, as with gypsum, possibly the mineral components of the soil may have maximum solubilities, in solutions of the more soluble salts of definite concentrations, far below the limit of solubility with respect to the readily soluble salts. Some work along this line has been undertaken by the Division. The subject is of such importance, and the field of investigation is so wide, that it is earnestly hoped that such work will commend itself to the attention of other investigators.

SOLUBILITY OF CALCIUM CARBONATE IN AQUEOUS SOLUTIONS OF CERTAIN ELECTROLYTES IN EQUILIBRIUM WITH ATMOSPHERIC AIR.

FRANK K. CAMERON and ATHERTON SEIDELL.

INTRODUCTION.

The experiments on the solubility of calcium carbonate were made in a similar manner to those described in the preceding papers. Since the solubility of the carbonates is dependent upon the partial pressure of the carbon dioxide in the gas phase in contact with the solution, the effort was made to bring these solutions to equilibrium with ordinary air. Air was therefore drawn through the flasks containing the solutions in contact with the calcium carbonate in the solid phase. The flasks were arranged in series with appropriate rubber and glass tube connections and a continuous stream of air drawn through by an aspirator attached to a hydrant. Before entering the solutions the air was drawn through a dilute solution of sulphuric acid to free it from any traces of ammonia or other impurities in the laboratory atmosphere. Precipitated calcium carbonate was used in order to

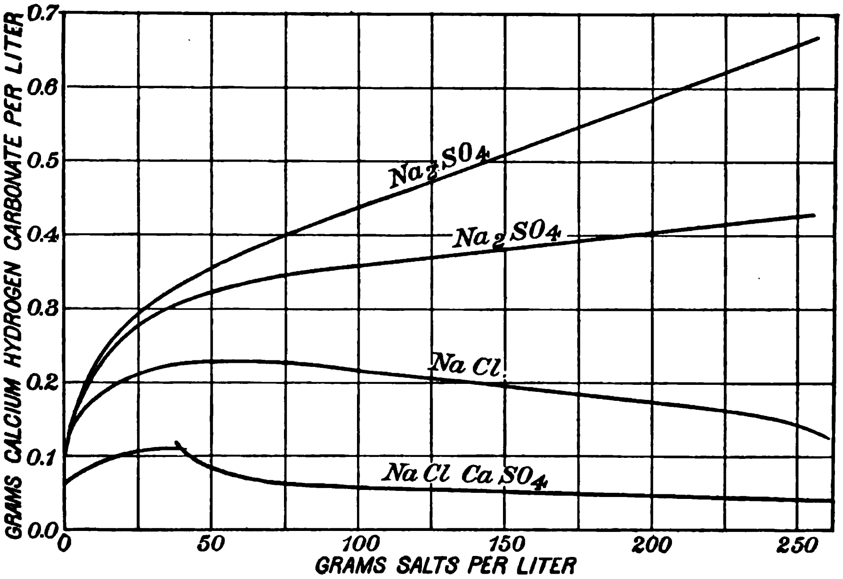

FIG. 9.—Diagram showing solubility curves for calcium bicarbonate in solutions of other salts. Results given in terms of grams per liter.

take advantage of the large surface exposed by the material in this form, and thus bring the solutions to equilibrium as quickly as possible. All the salts used were obtained from Baker and Adamson, were labeled C. P., and were found to be of a satisfactory degree of purity. As small changes of temperature did not produce any marked effect on the solubility of the calcium carbonate, and as the temperature of the laboratory held quite constant during the period when this work was done, it was not deemed worth while to make use of a constant temperature bath. .

Since it was found that the major part of the calcium went into solution as the hydrogen carbonate rather than as the normal carbonate, the calcium dissolved is stated in terms of the hydrogen carbonate. Of course the statements and charts in terms of reacting weights would be the same for either the normal or hydrogen carbonate.

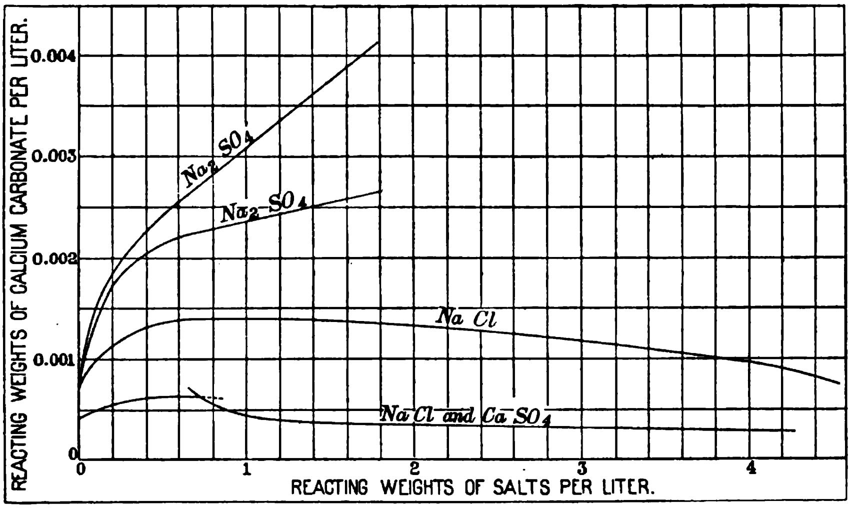

FIG. 10.—Diagram showing solubility curves for calcium bicarbonate in solutions of other salts. Results given in terms of reacting weights per liter.

In the accompanying figures (figs. 9 and 10) the calcium salt found to be soluble is plotted in all cases on the axis of ordinates and the amounts of other salt components of the solution on the axis of abscissas.

SOLUBILITY OF CALCIUM CARBONATE IN SODIUM CHLORIDE SOLUTIONS AT 25° C.

Air was passed through the solutions for twenty-seven days, the solutions being tested from time to time to determine when final equilibrium was reached, at which time they gave no reaction with phenolphthalein; that is to say, the solutions contained no normal carbonate dissolved in them.

At first sight this result appeared very surprising, but it is in line with the observations of Treadwell and Reuter, and with the observations made in the laboratories of this Division in the study of the equilibrium between the normal carbonate and hydrogen carbonate of calcium, described in the preceding pages of this bulletin.

The results obtained in the analyses of the solutions are given in the accompanying table, which is self-explanatory.

TABLE XX.—*Calcium hydrogen carbonate soluble in aqueous solutions of sodium chloride at 25° C. and in equilibrium with air.*

$Ca(HCO_3)_2$.		NaCl.	
Grams per liter.	R. wts. per liter.	Grams per liter.	R. wts. per liter.
0.1046	0.00065	0.000	0.000
.1770	.00110	9.720	.168
.2051	.00128	21.010	.362
.2152	.00134	30.301	.522
.2252	.00140	50.620	.872
.2212	.00138	69.370	1.195
.2172	.00135	98.400	1.695
.1971	.00123	147.400	2.540
.1569	.00095	234.500	4.040
.1227	.00076	262.300	4.520

These results are presented graphically in the accompanying figures.

The solubility curve presents a well-marked maximum point, corresponding to a solution containing in a liter about 56 grams, or 0.95 reacting weight of calcium hydrogen carbonate; that is to say, at the maximum point the corresponding solution would contain about 0.0561 gram of calcium—equivalent to 0.1402 gram of the normal carbonate. Hence it appears that the solubility of calcium carbonate under these conditions is about 80 times what it would be in pure water free from carbon dioxide.

In the series under consideration it was found that in the solution containing no sodium chloride there was 0.1046 gram per liter of calcium hydrogen carbonate, equivalent to 0.0592 gram per liter of the normal carbonate. Therefore the solubility of the calcium carbonate corresponding to the maximum point of the curve is 2.36 times its solubility in water in equilibrium with the air but containing no sodium chloride.

In general features the curve resembles the solubility curves for gypsum in solutions of sodium chloride or magnesium chloride; and the views expressed (in the discussion of the curves for those cases) as to the solution, transportation in the soil, and the subsequent reprecipitation of the slightly soluble calcium salt with changing concentration of the more soluble salts hold here. Of course the further complication—that the carbon dioxide in the gas phase in contact with the solution probably changes at the same time as the concentrations change with respect to the salts—enters and may effect the precipitation of the lime salt. But it should be remembered in this connection that calcium hydrogen carbonate is quite a stable compound in solution at ordinary temperatures, and does not yield up a part of its combined carbon dioxide as readily as do other hydrogen carbonates when the partial pressure of the carbon dioxide in the gas phase is lowered. It therefore seems probable that the concentrations of the solution with respect to sodium chloride would be the controlling factor in such a case as is under discussion.

SOLUBILITY OF CALCIUM CARBONATE IN SODIUM SULPHATE SOLUTIONS AT 24° C.

In this series of experiments normal carbonates were found to be present in the solutions of higher concentrations, even though successive examinations at intervals of weeks showed conclusively that the solutions had reached a final state of equilibrium and remained unchanged, even with the prolonged passage of air through them.

In the accompanying table the total amount of calcium in the solutions is given in terms of the equivalent in calcium hydrogen carbonate, although a part of the calcium should more properly be given as the normal carbonate. The actual amounts of the bicarbonate or hydrogen carbonate found in the solution are also given, and in the figure curves are plotted from both series of data. For purposes of comparison this is considered more desirable than giving the amounts of normal carbonate found, which could not well be illustrated in the figures.

Table XXI.—*Solubility of calcium carbonate in aqueous solutions of sodium sulphate at 24° C., and in equilibrium with air.*

Total calcium calculated as $Ca(HCO_3)_2$.		Calcium actually dissolved as $Ca(HCO_3)_2$.		Sodium sulphate.	
Grams per liter.	R. wts. per liter.	Grams per liter.	R. wts. per liter.	Grams per liter.	R. wts. per liter.
0.0925	0.00057	0.0925	0.00057	0.000	0.0000
.1488	.00092	.1488	.00092	2.800	.0191
.1729	.00107	.1729+	.00107+	5.235	.0356
.2330	.00145	.2210	.00137	11.730	.0831
.3240	.00201	.3020	.00188	36.860	.2612
.3960	.00246	.3440	.00214	74.010	.5245
.4580	.00285	.3660	.00228	116.100	.8228
.5630	.00350	.3940	.00245	184.200	1.3054
.5910	.00367	.4060	.00252	213.700	1.5146
.6650	.00413	.4300	.00267	255.900	1.8135

It will be observed that the curves do not show maximum points, but that the solubility of the calcium carbonate, both in the form of normal carbonate and of hydrogen carbonate, steadily increases with increasing concentration of sodium sulphate. It is especially worthy of note that the solubility of the calcium carbonate is very much greater in solutions of sodium sulphate than in solutions of sodium chloride, although in the former case the slightly soluble compound calcium sulphate is presumably formed, and in the latter the very soluble substance, calcium chloride. Even granting that practically all the calcium sulphate formed again unites with the sodium sulphate to form the soluble double sulphate, and making the further rather improbable assumption that this double sulphate dissociates in such a way as not to yield a calcium ion, the case does not become clear; for, at least in the higher dilutions, it would still be expected that the sodium chloride would have a greater solvent effect than the sodium sulphate. It is true that in the calculation of the data presented in this paper the reacting weight of sodium sulphate is based on the formula Na_2SO_4 instead of on the formula $1/2\ Na_2SO_4$. An inspection of fig. 10 will show that even on this latter assumption the sodium-sulphate curve would lie well above the sodium-chloride curve. Assuming, therefore, that the effect of the sodium ions would be the same in the two cases, it appears that the SO_4-ion has a greater effect than the Cl-ion in rendering the calcium carbonate more soluble.

Above a certain concentration (about 50 to 60 grams per liter) with respect to sodium sulphate the curves are practically straight lines; that is to say, the solubility of calcium carbonate in solutions above this concentration is directly proportional to the amount of sodium sulphate present. Assuming the mass law to hold, this indicates that at these higher concentrations the sodium sulphate dissociates as a binary electrolyte according to the scheme

$$\mathrm{Na\ NaSO_4} \rightleftarrows \overset{+}{\mathrm{Na}} + \mathrm{Na}\overset{-}{\mathrm{S}}\mathrm{O_4}$$

From this point of view it would seem that the relative effects of the $NaSO_4$-ions and the Cl-ions on the solubility of the calcium carbonate are to be compared, and that the first-mentioned ion is the more effective.

If it be assumed now that Ca-ion does not unite with the $NaSO_4$-ion to form a more complex ion, but does unite with the Cl-ion to form complex ions, the greater solvent effect of the sodium sulphate over that of the sodium chloride becomes intelligible. It is to be frankly admitted, however, that this train of reasoning involves a number of assumptions, and that, while some evidences from other sources may be adduced in support, it can be advanced only tentatively. It further accents the very unsatisfactory state of our knowledge of solutions, especially in other than states of high dilution.

SOLUBILITY OF CALCIUM CARBONATE IN SODIUM CHLORIDE SOLUTIONS AT 25° C. IN CONTACT WITH CALCIUM SULPHATE IN THE SOLID PHASE.

The solutions were found to contain no normal carbonates. The effect of the dissolved calcium hydrogen carbonate on the solubility of the calcium sulphate has been discussed in the preceding paper. By referring to the figures it will be seen that the effect of the dissolved calcium sulphate on the solubility of the carbonate was of the same general nature, but much greater in degree. With increasing concentration of sodium chloride the solubility of calcium carbonate gradually increases up to a maximum point, then drops suddenly, and finally decreases very gradually. The maximum solubility occurs in a solution containing about 40 grams per liter of sodium chloride. It will be remembered that the maximum solubility of the calcium sulphate, when calcium carbonate in the solid phase was also present, was in a solution containing from 80 to 85 grams per liter of sodium chloride.

While the effect of the presence of calcium carbonate on the solubility of calcium sulphate was shown to be slight in solutions containing less than 80 grams per liter of sodium chloride, it will be seen that the effect of the calcium sulphate on the solubility of the calcium carbonate is relatively great in all concentrations with respect to sodium chloride. Furthermore, the normal carbonate is entirely converted into hydrogen carbonate in the solutions. These facts are of great importance in considering the result of the application of calcium sulphate to soils containing calcium carbonate and sodium chloride and the much dreaded "black alkali" or sodium carbonate. Not only will the application of gypsum or land plaster to such soils reduce very much the amount of hydrogen carbonate in the soil solution and entirely eliminate the normal carbonate, but it greatly increases the amount of calcium soluble in the soil solutions. This fact alone would greatly increase the power of plants to resist the deleterious effects (other than an actual corrosion of the tissue) of an excessive amount of other soluble salts, as has been amply demonstrated by the results of some of the experiments made in the laboratory of this Division.

SUMMARY.

The results of this investigation show that sodium chloride in solution has an important rôle in causing the solution, transportation through the soil, and reprecipitation of calcium carbonate, and that this rôle is modified, but does not disappear, when calcium sulphate is present. The rationale of the application of gypsum or land plaster to soils containing "black alkali," or sodium carbonate, resulting from the action of sodium chloride upon calcium carbonate, is made apparent.

Sodium sulphate has been shown to have an astonishingly great effect on the solubility of calcium carbonate, the resulting solutions containing not only hydrogen carbonate, but normal carbonate as well. Further, there is no necessary precipitation of the lime carbonate with increasing concentration with respect to sodium sulphate; but the solubility of the lime carbonate steadily increases, with increasing amounts of sodium sulphate in the solution, up to the saturation point of this latter salt.

It is greatly to be regretted that time has not permitted an examination of the action of sodium sulphate on lime carbonate and sulphate simultaneously. The experience of the field parties of this Division that have worked on the alkali soils of the arid regions indicates that normal carbonates would not be present in the solution; but both the field work and an inspection of the analyses of the water-soluble constituents of soils containing these components indicate that hydrogen carbonate might be found to some considerable extent. It has, moreover, become important from the point of view of the effect of the soluble salts in the soil on plant culture to obtain an idea of the extent to which calcium in some form or other would be dissolved. The importance of the investigation for geological and drainage studies is evident. It is proposed to study this system at an early date.

CHEMICAL EXAMINATION OF ALKALI SOILS.

By Atherton Seidell.

INTRODUCTION.

In the course of the examination of several hundred alkali-soil samples in the laboratory of this Division, many difficulties have arisen in devising satisfactory methods for the systematic and rapid analysis of the portion of these soils readily soluble in water.

Some of the difficulties encountered have been mechanical, as the removal of suspended clay, which sometimes proves to be the source of a great deal of annoyance to the analyst. This disagreeable feature generally occurs when the total amount of soluble salts is very small, or when the alkali is small in amount and largely composed of soluble carbonates. The presence of the large quantities of dissolved organic matter sometimes found in the soil extracts, especially when much soluble carbonate is present, has given rise to a great deal of trouble, and has been given serious attention in the course of the analytical work of this laboratory. The equilibrium between normal carbonates and bicarbonates in aqueous solution has been found to have much importance in alkali studies, and the analytical problems attending it have been met in a satisfactory way.

Besides the examples cited many other points have been investigated and a large amount of information gathered in this laboratory along such lines. It is hoped that the results of the observations made and experience gained in this work may be of service to others who may have occasion to investigate chemically the alkali of arid soils.

The object of an "alkali analysis" is, first, to establish the chemical nature and relative composition of the constituents which form the readily water-soluble part of the soil; and, second, to obtain an approximate idea as to the amount of the readily soluble salts in the soil. The analytical operations, therefore, are confined to the investigation of the mineral substances contained in an aqueous extract of the soil. The amount of this soluble mineral matter may vary from almost nothing to 95 per cent or more of the soil sample.

It is evidently desirable that a criterion be established which would serve to distinguish the very soluble part of the soil as distinctly "alkali" from the less readily soluble portion which, for that very reason, can not be considered as alkali in the sense of being material harmful to plant growth. Although no such distinction can be sharply made between the very soluble constituents and those which are relatively insoluble, but which become soluble with increased amounts of water and extended length of time for solution, ~~there is sound~~ reason for believing that the part of the soil which is "alkali" may be determined within narrow limits for practically all alkali soils. The analytical methods involved will be described in the course of this paper.

PREPARATION OF THE SOLUTION.

It may be considered that the alkali of a soil is composed of relatively soluble salts; therefore, for its solution is required only a relatively small amount of water and brief space of time. Suppose that a given alkali-soil sample contains half of its weight of soluble salts; taking 50 grams of the sample for analysis, probably a few hundred cubic centimeters of water would be sufficient to dissolve the 25 grams of alkali present within the space of a few hours. If we carefully separate the undissolved soil from the solution and then add another portion of water and allow it to digest an equal length of time, the amount of material which is dissolved by this second operation is ordinarily a very small fraction of the amount which the first portion of water extracted from the soil.

It is obvious that when a soil contains a very small quantity of readily soluble salts a rather smaller amount of water will be sufficient to effect the solution of these salts than when the amount of alkali is considerable. However, by using a somewhat larger amount of water than is necessary to dissolve the salts present no material error is introduced, since each aliquot portion of this solution contains practically the same amount of alkali as an aliquot portion of the solution made with an amount of water which, though smaller, is still enough to dissolve all the alkali salts in the given soil sample.

In regard to the less soluble constituents, as, for instance, calcium sulphate, it is certain that the use of a larger amount of water will surely mean a larger relative proportion dissolved from the soil. This is practically true only beyond rather wide limits in the amount of water used.

If a soil solution made with a relatively small amount of water is considered, the concentration of the more soluble ingredients, such as chlorides, sulphates, and carbonates of sodium and potassium, may be quite large. Considering the effect of increasing concentration of these electrolytes upon the more insoluble ones, as illustrated by the increased solubility of gypsum in sodium-chloride solutions described elsewhere in this bulletin, it is evident that the amount of these relatively insoluble constituents of alkali in solution may be very greatly increased under such conditions of increased concentration of the more soluble electrolytes. Thus it may happen that the decrease, following the use of smaller amounts of water in making the soil solution, may in some degree compensate for the increase in the amounts of the more insoluble constituents dissolved with larger amounts of water.

In view of these considerations and for the sake of convenience and uniformity in the investigations upon all alkali-soil samples, it is the practice in this laboratory to place 50 grams of the soil sample for analysis in a large beaker and add to this one liter of distilled water. The solution is stirred vigorously several times and allowed to stand twenty-four hours. At the end of this time an amount of the supernatant liquid sufficient for the analysis is decanted through a filter paper into a flask.

The amount of water used in making the solution may appear to be somewhat liberal. Nevertheless it is evident that an error introduced in this manner would be of less importance than that which would result from using an insufficient amount of water, a consideration which should justify the procedure indicated. It seems altogether probable that the time limit of twenty-four hours allowed for the solution to come to final equilibrium with the material in the solid phase is rather too short, but it is not advisable to allow a longer time, since in many cases it is found that organisms collect in the solutions, and the indications are that the relative amounts of some of the constituents in the solution are markedly altered. In fact, it has been noticed that the growth of some of these organisms may be accompanied by the accumulation of soluble phosphates and, more frequently, nitrates.

The soil solution, made as above described, is quite clear whenever the amount of alkali in the soil is sufficient to flocculate the clay and smaller particles and so cause them to subside. This condition commonly occurs, but not always; for if the amount of alkali in the soil is very small, or small and largely composed of sodium carbonate, the clay will remain in suspension, and even when it is possible to separate it by filtration a very great amount of labor and time is required for its removal. The increased accuracy in the analytical results attained by filtering the muddy solution itself, instead of following the process described later, would hardly seem to justify the labor and time required for the filtration.

Quite recently Mr. Lyman J. Briggs, of this Division, has devised an apparatus by which clay can be successfully filtered from aqueous solutions at a rapid rate. It is expected that by the aid of this device even more satisfactory results will be attained than heretofore in the analysis of those alkali-soil samples which have so far presented the greatest difficulties.

Another difficulty will be experienced with the soil solution whenever the soil sample contains black alkali together with organic matter. In that event the solution may be quite free from suspended clay, etc., but on account of the dissolved organic matter it is frequently very dark, and in such a condition makes the volumetric determination of carbonates, bicarbonates, and chlorides exceedingly difficult. This subject will receive further attention in the detailed descriptions of the analytical processes.

ELECTRICAL RESISTANCE OF THE SOLUTION.

Before commencing the analysis of the soil solution, made as explained above, it is customary to take the electrical resistance of the solution by means of the ordinary Wheatstone bridge, or the modification of the same devised for the use of the field parties of this Division.

Since by this method the number of ions in solution is at once approximately determined, some idea is obtained of the concentration of the solution prepared for the analysis; it is therefore possible to select an aliquot portion which will contain an amount of the ingredient looked for, most suitable for manipulation in any given analytical process.

If the electrical resistance of the solution in the cell used is very high (about 1,000 ohms or more at room temperature) it is known that the solution contains a very small amount of soluble salts, and it will be necessary to use quite large aliquot amounts of the solution in order to obtain enough of the various constituents for accurate determinations. A resistance as high as 1,000 ohms indicates an amount of total solids approximately 0.02 gram per 100 cubic centimeters of solution. This information, as regards the amount of salts which corresponds to a given electrical resistance in a soil solution, is of course only approximate, but still as found by experience is accurate enough to be very useful indeed to the analyst. For example, it is found that when the electrical resistance of the soil solution is something less than 1,000 ohms but more than 500 a portion of the solution consisting of 200 cubic centimeters or more must be used for the determination of each of the possible ions; when the resistance is near 200 ohms a 100 cubic centimeter portion of the solution will suffice. Frequently it happens that the alkali sample examined will contain as much as half its weight of soluble material. In such a case the electrical resistance of the solution being very low (10 or 15 ohms) will indicate that the amount of salts in solution is very great and it will become necessary to dilute the portions intended for each determination. That the solution has been diluted sufficiently will be indicated by a resistance that indicates an amount of salts which can be most accurately determined in 100 cubic centimeters portions of the solution.

A word of caution, based upon experience in this laboratory, may be of service in this connection. It has been found that it is not advisable to dilute the portion of the original soil solution intended for carbonate and bicarbonate titrations, even when precaution is taken to boil the distilled water used for the dilution and thus free it from the carbonic acid which would cause the equilibrium between the carbonates and bicarbonates to be displaced in the direction of the bicarbonates. The results of the work of Dr. Cameron and Mr. Briggs, found elsewhere in this bulletin, verify this observation.

TOTAL SOLIDS DETERMINATION.

Total solids determinations, as made by evaporating to dryness in a platinum dish a given portion of the solution and weighing the desiccated material, are not only exceedingly unreliable, but are quite unnecessary for the analysis of soil solutions as practiced in this laboratory.

When such salts as are contained in alkali soil solutions are evaporated to dryness there will remain behind certain quantities of water of crystallization and also occluded water. The removal of this water is quite necessary for accurate determinations, but in many cases can be attained only by elevating the temperature of drying to dull redness. Also soil solutions frequently contain organic matter which requires a temperature of dull redness for its removal by combustion. Under the most favorable conditions, then, a temperature is required at which the volatilization of several of the constituents of the alkali will be possible. The results of total solids determinations may accordingly be very much too high or very much too low, depending in a great measure upon the temperature to which the material has been subjected.

Although confidence can seldom be placed in total solids determinations, they are sometimes serviceable in the estimation by difference of the amount of sodium when it has not been determined directly; also they may show a wide difference in results which would indicate that some of the possible ion determinations had been omitted. The sodium determinations are made directly, and the calculation as electrolytes of the ions determined insures the omission of none of the determinations. Therefore the total solids determination serves no important purpose in the analysis of alkali-soil samples as conducted in this laboratory, and is seldom made.

CARBONATE, BICARBONATE, AND CHLORINE DETERMINATIONS.

As indicated above, the eqilibrium between the carbonates and bicarbonates in the soil solution is very readily displaced, and to a large degree. For this reason it is advisable to make these determinations as soon after the preparation of the soil solution as possible.

The method in use in the laboratory of this Division for the determination of the carbonates and bicarbonates in the solution is a volumetric one devised by Dr. Frank K. Cameron for the use of the field parties. It is eminently adapted for accurate work, and is in all essentials a valuable laboratory method. The reactions involved and the practical applications of them are described in more detail by Dr. Cameron elsewhere in this bulletin.

The standard solution of acid potassium sulphate used contains 6.7584 grams of $HKSO_4$ per liter of solution, and is one-twentieth normal when considered in regard to replaceable hydrogen. To make the standard solution it is found advisable to dissolve, with heating, the weighed quantity of pure hydrogen potassium sulphate ($HKSO_4$) in a small amount of water and then make up the required number of liters. The solution may be standardized by titration against a standard ammonia or potash solution; it is not advisable, however, to precipitate the sulphion as barium sulphate and calculate the amount of the acid present from this determination. One cubic centimeter of the standardized $HKSO_4$ solution is equivalent to 0.002979 gram of carbonic acid ion (CO_3) or 0.003028 gram of hydrogen carbonic acid ion (HCO_3).

It seems most convenient in working with soil solutions, as previously described, to make the various determinations with 100 cubic centimeters aliquot portions; that is, to determine the grams of ions per each 5 grams of the soil. Therefore, unless it should otherwise be deemed inadvisable, as indicated by the electrical resistance of the solution, 100 cubic centimeters are placed in a beaker and titrated with the standard $HKSO_4$ solution for carbonates and bicarbonates and with standard N/10 $AgNO_3$ solution for chlorides.

To the measured portion of the soil solution is first added several drops of a solution of phenolphthalein; in the presence of carbonates a characteristic bright red color will result; in the absence of the red color the solution may be titrated for bicarbonates, as described later. In case the presence of carbonates is indicated by the red color the solution is immediately titrated with the standard $HKSO_4$ solution, just to loss of color, and the reading on the burette taken. This reading multiplied by the factor for one cubic centimeter of the solution (0.002979) gives the grams of normal carbonic acid ions (CO_3) present in the soil solution. By this reaction the normal carbonates are converted to bicarbonates by reacting with hydrogen potassium sulphate ($HKSO_4$).

In clear solutions the change can be accurately noted. In the cases where the solution is blackened by organic matter or clouded with suspended clay, etc., it sometimes becomes exceedingly difficult to obtain satisfactory readings. But it has been found that by providing a titration stand having a glass top and a white surface a few inches below, to reflect the light up through the solution, the correct observation of the color change is greatly facilitated. In such cases the average of several closely agreeing titrations will usually furnish a sufficiently accurate determination for all practical purposes.

When the titration for normal carbonates has been completed there is added to the solution one drop of a solution of methyl orange indicator, and, without refilling the burette, the titration is continued until the delicate change in the color of the solution, due to the liberation of free, undissociated methyl orange, is observed. The reaction involved is the conversion of the bicarbonates to the double sulphates of potassium and the other bases present with the liberation of H_2CO_3. Since methyl orange is not affected by the liberated H_2CO_3 in the solution, no change is observed until a very slight excess of $HKSO_4$ enters the solution. The complete conversion of all the bicarbonates present to sulphates is thus assured, and the amount of $HKSO_4$ necessary is an accurate measure of the amount of bicarbonates present.

The reading on the burette is taken at this change, and from this total reading is subtracted twice the first reading, and the resulting number of cubic centimeters is multiplied by the factor (0.003028) for HCO_3 ions.

The change in the color of the methyl orange at the end of the reaction is very slight, being usually only a shade of yellow slightly more pink than previous to the change—the color being a mixed one, resulting from the unchanged indicator in excess as well as from the changed indicator. The sharpness of the change is quite pronounced, and can be best seen when very small amounts of the indicator are used. Although great care is required for its detection, the completion of the reaction as indicated thus is accurately established.

Experience has amply demonstrated the advisability of using but small amounts of the methyl orange in the solution. The titration should be regarded as completed at the first change of color which can be detected in the indicator.

As might be supposed, anything but a clear solution being taken for this titration very greatly hinders the success of the determination; in some cases great accuracy is precluded. An indicator more suitable than methyl orange, for use with solutions which are colored, has been sought for, but with results not altogether satisfactory, although Congo red may be used to advantage under certain conditions, as pointed out by Dr. Cameron.[1] The problem requires the use of an indicator with the most marked differences in color in solutions which are alkaline and those which are acid. In addition, the strength of the indicator should be greater than carbonic acid, in order that the liberated H_2CO_3 should not itself affect the condition of the indicator during the reaction.

Another point worthy of attention, in regard to this volumetric method for the determination of carbonates and bicarbonates in aqueous solutions, is suggested by the experience gained in this laboratory. In addition to small particles of insoluble carbonates of alkaline earths, which are found in these muddy solutions, the clay itself may contain certain quantities of insoluble carbonates. When such soil solutions are titrated with the acid potassium sulphate, a part of the hydrogen potassium sulphate ($HKSO_4$) in the standard solution is used up in the reaction with these insoluble carbonates, and the apparent results for soluble carbonates will be somewhat too high. Errors due to this cause must be carefully guarded against, and require the greatest care for their avoidance.

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[1] See paper on The Estimation of Alkali Carbonates and Bicarbonates, p. 77.

It should be clearly understood in this connection that the ratio of normal carbonates to hydrogen carbonates, as determined in the laboratory, may lead to erroneous conclusions regarding the conditions in the field. It is certain that in transit from the field to the laboratory, with the drying out and other changes in the soil, the ratio of the normal carbonate to hydrogen carbonate must be materially changed. It is therefore advisable, when this ratio under field conditions is desired, that the determination should be made at the time the sample is taken. It is desirable that this ratio as determined in the field should accompany the statement of the analysis made in the laboratory. This has not always proved practicable in the past, but with a realization of the importance of the matter, it is intended that the field ratio shall be given in connection with the statement of analyses in future reports.

Upon the completion of the titration for the carbonates and bicarbonates the chlorides may be determined in the same solution by titration with standard silver nitrate. To the solution is added one drop of a saturated solution of potassium chromate (K_2CrO_4) and the standard one-tenth normal $AgNO_3$ solution slowly run in from the burette until the appearance of the red color, due to the formation of silver chromate, is recognized. This reaction is usually very sharp and the end may be most accurately determined. The number of cubic centimeters read off is multiplied by the factor (0.003518), and the result is the grams of chlor ions in the solution titrated.

OTHER DETERMINATIONS.

The only other acid ion found in alkali soil solutions to any large extent is sulphion (SO_4). The estimation of this in clear solutions is made by the usual method of precipitation and weighing as $BaSO_4$. In dealing with soil solutions which contain organic matter or suspended clay, etc., a very slight excess of hydrochloric acid is added and the solution boiled. In practically all cases the organic matter or clay will flocculate and can be filtered from the solution. There seems to be no appreciable error introduced by the solution of the insoluble sulphates from the suspended matter with the very small amount of hydrochloric acid which is required to bring about flocculation.

This method of clearing solutions of suspended matter is not permissible, when the solutions are intended for the basic ion determinations, on account of the relatively large amounts of the bases which may be dissolved from the suspended matter by the hydrochloric acid. For this reason the filtrate from the sulphion (SO_4) determination is to be used for the sodium (Na) and potassium (K) ion determinations only when the original soil solutions is clear of suspended matter.

In addition to the four acid ion determinations described above, a qualitative examination is always made for nitrates and phosphates. When it appears that an amount of these constituents is present sufficient for quantitative determination, the nitrates are determined by the Ulsch method and the phosphates by the molybdate method.

The occurrence of borates in alkali soils which give promise of ever having any agricultural value is so rare that it very seldom happens that such a determination is made necessary in the work of this laboratory. Although the experience with this determination in the laboratory of this Division has been somewhat limited, the Gooch method has yielded the most satisfactory results.

The amount of silicic acid ions (SiO_3) which will be dissolved from an alkali soil by water is usually inappreciable; hence it is seldom found necessary to make the determination in the soil solution. Occasionally it is desirable to make this determination, especially in solutions made from soils containing much soluble carbonate. The determination is then carried out in the conventional way by adding an excess of hydrochloric acid to the solution and evaporating to dryness several successive times to precipitate the silica in an insoluble form suitable for separation by filtration. Some care must be taken that gypsum does not precipitate at the same time and interfere with the determination, but this latter difficulty is seldom encountered.

Whenever it is necessary to obtain the soil solution free from suspended material for some of these determinations, especially from the basic constituents, besides the device of Mr. Briggs referred to above, two methods of procedure have suggested themselves and have been tried in this laboratory.

The muddy solution was evaporated to dryness and the dish gently heated to cake the clay. The material was then taken up with water and filtered. Occasionally it was necessary to repeat the process in order to get rid of all the suspended material. A serious objection to the procedure arose whenever calcium salts and carbonates or sulphates were present to any extent; for in such cases a considerable portion of the calcium would be precipitated as the carbonate or sulphate, and, while they would undoubtedly go into solution again in the course of time, the rate of solution for these salts is so slow that there can hardly be any question that much of the calcium was not taken up but left in the clay residue. The same general considerations, but probably to a lesser degree, apply also to the magnesium.

A better method than this consists in flocculating the suspended matter in the solution with a very small amount of ammonia alum and then filtering off the clear solution. The experience in this laboratory has shown that both of these methods are open to objections. The experimental difficulties are less in using the latter method, and the errors are usually negligible; therefore this method is to be preferred.

The analytical methods for the base ion determinations in soil solutions, when they are free from suspended matters are those most commonly applied. Calcium is precipitated as the oxalate and, after blasting, weighed as the oxide; magnesium is determined as magnesium pyro-phosphate; sodium and potassium are separated together in the usual manner and weighed as the chlorides; the potassium is separated from the sodium as potassium platinic chloride.

The shortcomings of this last method are well known to all, and it is to be regretted that a more satisfactory analytical method for the determination of sodium and potassium has not been devised. In spite of the fact that the very accurate determination of sodium is almost impossible, it is apparent that sodium determinations made in this way are much to be preferred to those statements of results which indicate the amount of sodium present by "difference."

CALCULATION OF ANALYSES.

The analytical methods, as previously described, give the grams of each of the ions determined in 100 cubic centimeter portions of the soil solution, or the grams of ions per each 5 grams of the soil sample. These results are tabulated and the sum, after being divided by 5 and two decimal places pointed off to the right, gives the percentage of "alkali" in the soil sample.

Since the analysis has been made upon an aqueous solution of a number of salts, the acid ions determined must be exactly sufficient to combine with the base ions determined regardless of the manner in which the combinations are made. The analysis is regarded as satisfactory when this condition is fulfilled and duplicate determinations are deemed necessary only when there is an error in the analysis—indicated by a discrepancy in the calculation of the ion determinations as electrolytes.

The manner in which the ions are combined is arbitrary, and it must be strongly urged that great care be exercised in drawing conclusions in regard to an alkali soil from the consideration of an analysis expressed as salts, although much useful information can sometimes be obtained from this source.

No special justification is claimed for the method of calculating the analysis as practiced in this laboratory. It is evident that the ions as found in the soil solution really exist in all the combinations possible as well as in the dissociated state. It is merely a matter of convenience that justifies the combination of the base ions in the following order: Ca, Mg, K, and Na with the acid ions in the following order: SO_4, Cl, CO_3, and CHO_3. When these calculations are completed the total of the electrolytes thus stated must be equal to the total of the ions as actually determined.

Finally, from these results the percentage composition of the alkali, as expressed in ions and electrolytes, is calculated. The results are stated in this form, since it is the relative composition of the alkali which the analysis is mainly designed to make clear.

SUMMARY.

The method for the examination of alkali soils as described in this paper, presents the following features:

1. The aqueous solution of the soil alkali is made under similar conditions in all cases.
2. The electrical resistance of the soil solution is used in facilitating the analytical processes.
3. A direct determination of the total solids in the soil solution is not made.
4. A unique, satisfactory, and accurate volumetric method is used for the determination of carbonates and bicarbonates.
5. All the constituents, including sodium, are determined directly, and no results are obtained by difference.
6. The possible necessity for duplicate determinations is made evident by the calculation of the results obtained.
7. Finally, the report of the analysis includes the percentage of alkali present in the soil and the relative percentage composition of this alkali; it is stated in terms of the possible ions present in the solution as well as their combinations as electrolytes.

For the convenience of those who may wish to apply the methods for alkali soil examination here described, there is appended at the end of this paper a table of the factors, with the logarithms of the same, found necessary for the calculation of the analytical results.

Factors used for calculation of alkali soil analyses.

		Factor.	Log.			Factor.	Log.
$BaSO_4$	SO_4	0.4114	0.6142	K_2SO_4	K_2	0.4488	0.6521
	SO_3	.3429	.5351		SO_4	.5512	.7414
$CaSO_4$	Ca	.2943	.4687	K_2CO_3	K_2	.5659	.7528
	SO_4	.7057	.8486		CO_3	.4341	.6376
$CaCO_3$	Ca	.4003	.6024	K (HCO_3)	K	.3906	.5918
	CO_3	.5997	.7790		HCO_3	.6094	.7849
Ca $(HCO_3)_2$	Ca	.2471	.3929	KCL	K	.5246	.7198
	$(HCO_3)_2$	.7529	.8767		Cl	.4754	.6771
$CaCl_2$	Ca	.3616	.5582	KNO_3	K	.3867	.5874
	Cl_2	.6384	.8051		NO_3	.6133	.7877
Ca $(NO_3)_2$	Ca	.2441	.3876	K_2PtCl_6	K_2	.1611	.2071
	$(NO_3)_2$	.7559	.8784		KCl	.3070	.4871
CaO	Ca	.7145	.8540	Na_2SO_4	Na_2	.3243	.5109
$MgSO_4$	SO_4	.7982	.9021		SO_4	.6757	.8298
	Mg	.2018	.3049	Na_2CO_3	Na_2	.4344	.6379
$MgCO_3$	Mg	.2880	.4594		CO_3	.5656	.7525
	CO_3	.7120	.8525	Na (HCO_3)	Na	.2742	.4381
Mg $(HCO_3)_2$	Mg	.1659	.2199		HCO_3	.7258	.8608
	$(HCO_3)_2$	.8341	.9213	NaCl	Na	.3940	.5955
$MgCl_2$	Mg	.2551	.4067		Cl	.6060	.7825
	Cl_2	.7449	.8721	$NaNO_3$	Na	.2710	.4330
Mg $(NO_3)_2$	Mg	.1637	.2141		NO_3	.7290	.8627
	$(NO_3)_2$	.8363	.9224	Fe_2O_3	Fe_2	.7001	.8452
$Mg_2P_2O_7$	Mg	.2181	.3387		O_3	.2999	.4770

	Factor.	Log.
	Grams.	
1 c.c. $\frac{N}{10}$ $AgNO_3$ (16.868 grams per liter) = Cl	0.003518	0.5463
1 c.c. $\frac{N}{20}$ $HKSO_4$ (6.7585 grams per liter) = CO_3	.002979	.4740
= HCO_3	.003028	.4811

ESTIMATION OF CARBONATES AND BICARBONATES IN AQUEOUS SOLUTION.

By Frank K. Cameron.

NATURE OF THE PROBLEM.

The estimation of carbonates and bicarbonates in aqueous solution is a problem frequently presented in this laboratory. It has been found that the method first suggested by Winkler, of which Küster[1] has given a good description, is very well adapted for this purpose when modified as I have suggested.[2] The method depends upon the fact that carbonic acid ($=CO_3$) or hydrogen carbonic acid ($-HCO_3$) is a stronger acid than phenolphthalein but weaker than methyl orange. If phenolphthalein be added to a solution containing alkaline carbonates it will show the well-known alkaline reaction, on account of the hydrolized free base in the solution, and will continue to do so until all the free base which may be formed by the hydrolysis of the normal carbonate has been neutralized. The hydrogen carbonates or bicarbonates do not themselves show an alkaline reaction with phenolphthalein; but if methyl orange be added to the solution, being a stronger acid than the carbonic acid, it will show its characteristic reaction toward the base as though carbonic acid were not present, qualitatively at least.

DESCRIPTION OF THE METHOD.

The mechanism of the method consists in titrating with a standard solution of hydrogen potassium sulphate (6.7585 grams $HKSO_4$ per liter), using phenolphthalein as indicator until loss of color. The reading taken at this point gives the equivalent of normal carbonates present. Methyl orange is then added and the titration continued—without refilling the burette, but starting from the point where the last reading was taken—until the change of color, and the reading again taken. This final reading, *less twice* the first reading, gives the equivalent of the bicarbonates present. This procedure has become especially important, since it has been shown from the work of others[1] and by extended investigations in this laboratory that solutions of carbonates almost invariably contain bicarbonates as well, especially when allowed to stand in contact with the air. Under such circumstances a definite equilibrium between the carbonates and bicarbonates is established, depending upon the concentration and temperature. Moreover, the distilled water in most laboratories, especially when first prepared, is rich in dissolved carbonic acid, so in making up solutions of alkaline carbonates, bicarbonates are at once formed.

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[1] Zeits. für anorg. Chem., 13, 127 (1896).

[2] Report 64, U. S. Department of Agriculture; Am. Chem. Jour., 23, 471 (1900).

Attention has been called by Mr. Briggs to the fact that considerable quantities of carbon dioxide are absorbed or condensed on solid surfaces, such as glass beads, soil grains, etc. When such surfaces are washed with an alkaline solution bicarbonates will be formed, and if not too concentrated with respect to the normal carbonate the solution may lose its alkaline character (toward phenolphthalein, for instance), a fact amply verified by experience. This process is probably an important one in nature, especially when quantities of sodium carbonate or black alkali occur in the soil. The composition of the solution formed under such conditions is readily determined by the method under discussion, and this is regularly done by the field parties of this division when working in alkali regions. Since the method has come into somewhat extended use in the hands of nonprofessional chemists, certain difficulties and misconceptions have developed which make it seem desirable to give more explicit explanations, and this opportunity is taken to do so.

To obtain a specimen of the acid of the exact composition indicated by the formula $HKSO_4$ is probably a very difficult matter, and the effort to do so is not worth while, as has been pointed out in another place. A reasonably pure substance will answer very well and can readily be obtained from the dealers. For the accurate work in this laboratory the standard acid solution is always compared with another standard solution, generally by titrating both it and a carefully prepared tenth normal (N/10) HCl solution against a solution of potassium hydrate free from carbonates. In field work experience has shown that the solutions made from weighed portions of the chemically pure material obtained from a responsible dealer is sufficiently accurate for all purposes.

THEORETICAL BASIS OF THE METHOD.

For practical purposes hydrogen potassium sulphate may be regarded as a monobasic acid which will yield the ions $\overset{+}{H}$ and $\overset{-}{KSO_4}$ although it is well known that this is not strictly true. On this assumption a solution containing 6.7585 grams of the acid per liter will be a twentieth normal (N/20) solution; that is, containing a 0.05 gram equivalent of hydrogen per liter, or 1 gram equivalent of hydrogen in 20 liters of solution. Since the reaction with sodium carbonate is expressed by the equation

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[1] That this is true for the carbonates of magnesium has been suggested by Treadwell and Reuter (Zeits. für anorg. Chem., **17**, 178 (1898)). That it is true for the sodium and potassium salts has been clearly demonstrated by the work of Mr. L. J. Briggs and the author.

$$HKSO_4 + NaCO_3 = NaKSO_4 + NaHCO_3$$

[Phenolphthalein as indicator].

it is evident that one reacting weight of $HKSO_4$ is equivalent to one reacting weight of normal sodium carbonate. But sodium carbonate (Na_2CO_3) is a bibasic salt, and 1 cubic centimeter of the twentieh normal (N/20) acid will be equivalent to 1 cubic centimeter of a tenth normal (N/10) solution of the carbonate. To obtain the weights in grams of the several equivalents multiply the number of cubic centimeters of acid used by the following factors:

Normal sodium carbonate, Na_2CO_3	0.005261
Total sodium combined as normal carbonate	.002288
Sodium converted to form of bicarbonate during the titration	.001144
CO_3 ions combined as normal carbonate	.002978

With sodium bicarbonate the reaction is expressed by the equation:

$$HKSO_4 + NaHCO_3 = NaKSO_4 + H_2CO_3$$

[Methyl-orange as indicator].

Again we have one reacting weight of the acid equal to one reacting weight of the sodium hydrogen carbonate; but as we do not regard this latter substance (in this connection) as an acid but as a sodium salt of a monobasic acid $H(HCO_3)$, we have 1 cubic centimeter of the twentieth normal (N/20) acid equivalent to 1 cubic centimeter of the twentieth normal (N/20) salt solution. It is obvious that for each reacting weight of sodium carbonate originally in the solution there will be a reacting weight of sodium hydrogen carbonate after the titration with phenolphthatein as indicator. Therefore as many cubic centimeters of acid as were required for the titration with phenolphthalein must be added to neutralize this sodium hydrogen carbonate thus formed before the titration for this salt originally present may properly be begun. This will explain the directions given above for reading the burette. To obtain the weight in grams of the several equivalents, multiply the number of cubic centimeters of acid required by the factors:

Sodium hydrogen carbonate, $NaHCO_3$	0.004172
Sodium combined as hydrogen carbonate	.001144
HCO_3-ions combined as hydrogen carbonate	.003028

With the potassium salts, both the carbonate and bicarbonate, the reactions are strictly analogous to those with the sodium salts, and precisely similar reasoning holds throughout. The statements in the foregoing paragraphs need be changed only as to the absolute values of the factors, which may be tabulated as follows:

Titration of normal carbonate.

[Phenolphthalein as indicator.]

Normal potassium carbonate, K_2CO_3	0.006860
Total potassium combined as normal carbonate	.003882
Potassium converted to the form of bicarbonate during the titration	.001942
CO_3-ions combined as normal carbonate	.002978

Titration of bicarbonate.

[Methyl orange as indicator.]

Potassium hydrogen carbonate, $KHCO_3$	0.004969
Potassium combined as hydrogen carbonate	.001942
HCO_3-ions combined as hydrogen carbonate	.003028

MODIFICATIONS FOR ALKALINE EARTHS.

With solutions of magnesium carbonate and bicarbonate certain differences are introduced of which account must be taken. With magnesium carbonate the reaction appears to be expressed by the equation

$$HKSO_4+MgCO_3=MgSO_4+KHCO_3$$

[Phenolphthalein as indicator.]

One reacting weight of the acid is equivalent to one reacting weight of the magnesium carbonate. Magnesium carbonate being a bibasic salt, 1 cubic centimeter of the twentieth normal (N/20) acid is equivalent to 1 cubic centimeter of a tenth normal (N/10) solution of magnesium carbonate. The amount in grams of the constituents determined can be obtained with the following factors:

Normal magnesium carbonate, $MgCO_3$	0.004183
Magnesium combined as normal carbonate	.001205
CO_3-ion combined as normal carbonate	.002978

As will be seen from the last equation given, an equal amount of the acid to that required for the titration with phenolphthalein as indicator must be added to neutralize the potassium hydrogen carbonate formed, before the titration for magnesium bicarbonate with methyl orange as indicator may proceed.

The reaction with magnesium bicarbonate apparently takes place in two stages:

$$HKSO_4+Mg(HCO_3)_2=MgSO_4+H_2CO_3+KHCO_3.$$

But the potassium hydrogen carbonate resulting from the reaction, reacts as an alkali toward the stronger electrolyte, methyl orange, which is used as an indicator for this titration. A further addition of the acid must be made to neutralize this salt, according to the equation:

$$HKSO_4+KHCO_3=K_2SO_4+H_2CO_3.$$

If the complete reaction as indicated by the two equations given be brought together in one expression we have:

$$2HKSO_4+Mg(HCO_3)_2=MgSO_4+K_2SO_4+H_2CO_3.$$

From this last equation it appears that two reacting weights of the acid are required to balance one reacting weight of the *bibasic* magnesium bicarbonate. Therefore, 1 cubic centimeter of the twentieth normal (N/20) acid will be equivalent to 1 cubic centimeter of a twentieth normal (N/20) solution of the salt. To determine the weight of the salt equivalents determined, the following factors may be used:

Magnesium bicarbonate, $Mg(HCO_3)_2$	0.0036305
Magnesium combined as bicarbonate	.0006025
HCO_3-ion combined as bicarbonate	.0030280

The reactions with solutions of calcium salts are strictly analogous to those with the magnesium salts. The factors may be tabulated as follows:

Titration of normal carbonate.

[Phenolphthalein as indicator.]

Normal calcium carbonate, $CaCO_3$	0.004966
Calcium combined as normal carbonate	.001988
CO_3-ion combined as normal carbonate	.002978

Titration of bicarbonate.

[Methyl orange as indicator.]

Calcium bicarbonate, $Ca(HCO_3)_2$	0.004022
Calcium combined as bicarbonate	.000994
HCO_3-ion combined as bicarbonate	.003028

MODIFICATIONS IN PRESENCE OF A FREE BASE.

The method is readily applicable to a case where there is an excess of free bases. The titrations are made as before, but in this case the difference between the final reading and the first reading gives the equivalent of normal carbonates present; and the first reading, less this difference, gives the equivalent of free base present. Titrating with phenolphthalein as indicator, the free base—for instance, sodium hydroxide—is first neutralized according to the equation:

$$HKSO_4 + NaOH = NaKSO_4 + H_2O;$$

but the solution will still show an alkaline reaction from the sodium carbonate, which will not disappear until the carbonate has been converted into bicarbonate according to the equation already given. But if methyl orange be now added and the titration continued, just so much acid will be required to neutralize the bicarbonate as was required to convert the normal carbonate to bicarbonate. Since in both titrations the reactions take place, reacting weight for reacting weight, 1 cubic centimeter of the twentieth normal (N/20) acid is equivalent to 1 cubic centimeter of a twentieth normal (N/20) salt solution. In the case of magnesium compounds the titration, with phenolphthalein as indicator, involves the reactions given in these equations:

$$2HKSO_4 + Mg(OH)_2 = MgSO_4 + K_2SO_4 + 2H_2O$$

and

$$HKSO_4 + MgCO_3 = MgSO_4 + KHCO_3.$$

If methyl orange be now added, and the titration continued, the reaction will be between the potassium hydrogen carbonate formed in the first titration and the standard acid. This reaction, we have already seen, takes place reacting weight for reacting weight. And, as will be seen from the equation, one reacting weight of the potassium hydrogen carbonate is equivalent to one reacting weight of the magnesium carbonate, and it may be assumed that 1 cubic centimeter of the twentieth normal (N/20) acid is equivalent to 1 cubic centimeter of the tenth normal (N/10) solution of the bibasic magnesium carbonate. But with respect to the magnesium hydrate, the equation shows that two reacting weights of the acid are equivalent to one reacting weight of the hydrate. Therefore 1 cubic centimeter of the twentieth normal (N/20) acid is equivalent to 1 cubic centimeter of a twentieth normal (N/20) solution of the bibasic magnesium hydrate. From a consideration of these facts the following factors were calculated:

Table of factors.

Sodium hydrate, NaOH	0.001988
Sodium combined as hydrate	.001144
Sodium carbonate, Na_2CO_3	.005261
Sodium combined as carbonate	.002288
Potassium hydrate, KOH	.002785
Potassium combined as hydrate	.001941
Potassium carbonate, K_2CO_3	.006860
Potassium combined as carbonate	.003882
Magnesium hydrate, $Mg(OH)_2$	.0014465
Magnesium combined as hydrate	.0006025
Magnesium carbonate, $MgCO_3$	.004183
Magnesium combined as carbonate	.001205
Calcium hydrate, $Ca(OH)_2$	.001838
Calcium combined as hydrate	.000994
Calcium carbonate, $CaCO_3$	.004966
Calcium combined as carbonate	.001988

EXTENSION OF THE METHOD TO INCLUDE ESTIMATION OF CHLORIDES.

One great advantage in using this method lies in the fact that chlorides, if present in the original solution, can be readily estimated volumetrically in the same sample taken for the estimation of the carbonates or the free bases.[1] Normal carbonates, or the free bases, if present, would of course interfere with a titration for chlorides with standard silver-nitrate solution. But when the titration with the standard hydrogen potassium sulphate ($HKSO_4$) solution has been completed, these objectionable components have been converted either to neutral sulphates or to bicarbonates. Neither of these will interfere with the precipitation of chlorine by the silver salt. Silver sulphate, as is well known, is a readily soluble salt. It has been established that silver bicarbonate (if it exists at all[2]) is at least twenty-three times as soluble as the slightly soluble normal carbonate.[3] But the important point in this connection is that it may be regarded as a fairly soluble salt, and, under the conditions likely to be met in analytical practice, does not interfere with the precipitation of chlorine by silver nitrate. It is only necessary, then, on the completion of the titration with the acid potassium sulphate solution, to add a single drop in excess to prevent any inversion[4] of the bicarbonates, then add a drop or two of potassium chromate as an indicator, and proceed with the titration with the silver nitrate solution. The precaution of adding a drop or two in excess of the hydrogen potassium sulphate solution is often an important one. It can seldom or never cause any embarrassment by affecting the solubility of the silver chromate at the end of the titration, when used in the amount indicated. On the other hand, it is to be remembered that potassium chromate, consisting of a strong base-forming metal with a comparatively weak acid, is considerably hydrolized in water, giving an alkaline reaction. The desirability of preventing this, especially in such a case as we are considering, is obvious.

It may be worthy of remark here that our experience indicates the desirability of using very small quantities of the chromate as indicator—as little, in fact, as will give a distinct color to the solution, although this will vary somewhat with the eye of the individual analyst. At the end of the reaction between the chloride and the soluble silver salt, if any considerable amount of the chromate be present, the strong yellow color it imparts to the solution, together with that of the red silver chromate first formed, gives a disagreeable mixed color of an indefinite shade, and to accomplish a sharp titration is very difficult under such circumstances.

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[1] Am. Chem. Jour. 23, 481 (1900).

[2] Mendeleeff, in his Principles of Chemistry, implies that silver hydrogen carbonate can not exist.

[3] At 21° C. the solubility of silver hydrogen carbonate ($AgHCO_3$) is 0.942 gram per liter; silver carbonate (Ag_2CO_3), 0.0399 gram per liter.

[4] See Am. Chem. Jour. 23, 471 (1900).

OBJECTIONS TO THE METHOD.

Küster[1] has urged as an objection to Winkler's method that the end point of the titration, with methyl orange as indicator, is too uncertain. Here, again, the difficulty can at least be much diminished by using a minimum amount of the indicator. Experience in this laboratory indicates that the trouble in this case is also owing to a mixed color, arising from the color of the unchanged indicator blending with and more or less masking the color of the changed indicator. Several workers in this laboratory have had frequent occasion to use the method, and, after very little practice, determinations made quite independently show remarkably good agreement. A long and careful examination of this point has demonstrated that by using very small quantities of the methyl orange the most accurate results are obtained by titrating just to the first appearance of change of color. This experience has been very fully confirmed by that of other workers in this laboratory and is in direct opposition to the views of Küster, who advises titrating to some definite tint. As an example, some results are given in Table XXII, made with a solution of sodium carbonate prepared from chemically pure material (obtained from Eimer and Amend) and distilled water, which had previously been boiled for a long time to get rid of any excess of dissolved carbon dioxide. These results are not especially selected, but are given just as they were made, with the ordinary care and without rejecting any determinations.

The first column gives the number of cubic centimeters of the carbonate solution taken; the second, the number of cubic centimeters of the standard $HKSO_4$ solution required to titrate to loss of color with phenolphthalein as indicator; the third, the number of cubic centimeters of the standard acid required after adding the methyl orange and continuing the titration; the fourth, the difference of the two titrations, respectively, and the fifth, the amount required for 1 cubic centimeter, using methyl orange as the indicator.

TABLE XXII.—*Titrations of* Na_2CO_3 *solution with* N/20 $HKSO_4$, *using very small quantities of methyl orange as indicator.*

Quantity of Na_2CO_3 solution.	Quantity of N/20 $HKSO_4$ required.		Differences in the titrations.	N/20 $HKSO_4$ = 1 c.c. Na_2CO_3 solution, methyl orange as indicator.
	With phenolphthalein.	With methyl orange.		
c. c.	*c. c.*	*c. c.*	*c. c.*	*c. c.*
10	4.60	9.15	4.55	0.915
10	4.55	9.13	4.58	.913
10	4.60	9.12	4.52	.912
25	......	22.85	......	.914
				.9135

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[1] Loc. cit.

The results here presented must be regarded as quite satisfactory, and it would seem that used in the way just indicated satisfactory results can be obtained with methyl orange. Nevertheless, it must be admitted that the difficulty in its use is a real one, and is greater with some individuals than with others, as the color change is certainly a difficult one for many analysts to distinguish even under the most favorable conditions.

CONGO RED AS AN INDICATOR.

The desirability of finding a more suitable indicator became evident, all the more so in view of certain difficulties experienced by our field parties working in the alkali or arid regions of the West. This method now forms a part of their regular equipment for the examination of alkali soils in the field. But very frequently they are obliged to deal with the turbid solutions containing much suspended clay in which the color absolutely precludes the use of the methyl orange, unless large quantities be used and a decided excess of acid be run in to obtain a sufficiently definite color change. After various attempts to find an acid indicator stronger than carbonic acid that would give well-marked color changes, it was at last found that "Congo red" fulfilled the requirements quite satisfactorily. On the basis of some preliminary experiments it has been adopted by the field parties, with generally satisfactory results. An examination of the conditions best adapted to its use was deemed advisable, however, and the results are here presented.

Congo red is now on the market in considerable quantities. It can be obtained readily in very satisfactory condition, and is now widely used as an indicator, to a great extent taking the place of litmus. The color change is very similar to that of litmus, but more marked, and in the reverse order, being a strong red in alkaline solutions and a heavy blue or blue-black in acid solutions. For the purpose of the experiments here described a solution of sodium cabonate (Eimer and Amend, c. p.) of unknown strength was prepared, using distilled water which had been boiled for a long time to expel carbon dioxide. The results are presented in tables XXIII, XXIV, XXV, and XXVI. Those given in Table XXIII were obtained by an assistant in the laboratory, who had had no previous experience with the method; titrations Nos. 1 and 2, made in beakers, being intended merely as rough determinations to familiarize him with the method. The other titrations were made in porcelain dishes. No titrations whatever have been discarded, all being presented as they were obtained and without preference. The methyl orange for all the titrations in which its use is described in this paper was prepared by dissolving 1 gram in 200 cubic centimeters of water. A single drop only was used for a titration. Even smaller quantities would have been preferable. The Congo red was prepared by making a saturated solution in 30 per cent alcohol. The first column of the table gives the number of the experiment; the second column, the number of cubic centimeters of the sodium carbonate solution; the other columns, the number of cubic centimeters of the hydrogen potassium sulphate solution required, the indicator used being stated at the head of the column:

Table XXIII.—*Titrations of Na_2CO_3 solution with N/20 $HKSO_4$ for the purpose of comparing methyl orange and Congo red as indicators.*

No.	Quantity of Na_2CO_3 solution.	Quantity of N/20 $HKSO_4$ required—		
		With phenol-phthalein.	With methyl orange.	With Congo red.
	c. c.	c. c.	c. c.	c. c.
1	25	21	42	......
2	25	......	42.1	......
3	25	20.4	42.1	......
4	25	20.9	42.05	......
5	25	20.65	42.05	......
6	25	20.5	......	42.3
7	25	20.8	......	42.3

A series of titrations was then made to determine at what point the titration should cease after the color change began. It was clearly demonstrated that the best procedure was to titrate until no further change of color could be observed—in striking contrast to what was found advisable when methyl orange was used. This point established, the titrations presented in Table XXIV were made, the statement in brackets at the right referring to the amounts of indicator used. The titrations were made in porcelain dishes:

Table XXIV.—*Titrations of Na_2CO_3 solution with N/20 $HKSO_4$, using varying amounts of Congo red as indicator.*

No.	Quantity of Na_2CO_3 solution.	Quantity of N/20 $HKSO_4$ required		
		With phenol-phthalein.	With methyl orange.	With Congo red.
	c. c.	c. c.	c. c.	c. c.
8	25	20.6	42.10	......
9	25	20.6	......	42.05 [2 drops]
10	25	......	......	42.05 [1 drop]
11	25	......	......	42.15 [4 drops]
12	25	......	......	41.7 [1 c.c.]
13	25	......	......	41.6 [1 c.c.]

The low results obtained in experiments 12 and 13 were obviously due to inability to follow the color change in the presence of such densely colored solutions as were obtained with such amounts of indicator in a porcelain dish. Two titrations were then made in glass beakers so arranged that light passed through the solutions from the bottom. The results are given in Table XXV:

Table XXV.—*Titrations of Na_2CO_3 solution with $N/20$ $HKSO_4$, using large quantities of Congo red as indicator.*

No.	Quantity of Na_2CO_3 solution.	Quantity of $N/20$ $HKSO_4$ required.
	c. c.	*c. c.*
14	25	42.10 [1 c.c.]
15	25	42.05 [1 c.c.]

It would appear from the results given in Tables XXIV and XXV that very satisfactory titrations can be made with Congo red as indicator, and that considerable quantities of the indicator may be used if care be taken to pass a strong beam of light through the solution. This point is one of great importance where the method is used in the field—for instance, in solutions which hold a considerable quantity of matter in suspension, often strongly colored. The temptation to use a large quantity of indicator is often great under such circumstances, and the tendency to obtain too low readings on account of the inability to clearly distinguish the end point of the reaction in the dark-colored opaque fluid resulting, is equally great. This fact has been amply verified by general experience with the method. Further tests were made in the laboratory by suspending clay in some sodium carbonate solutions and titrating with various amounts of the indicator present. While fairly concordant results were obtained, there was an undoubted tendency toward low readings when much of the indicator was present.

Solutions were now prepared, each containing 10 cubic centimeters of the sodium carbonate solution already described and 5 cubic centimeters of a N/5 sodium chloride solution. These were titrated in the usual way. After completing the titration with the hydrogen potassium sulphate solution a drop or two of a saturated solution of potassium chromate was added. The strong yellow color appeared at once, with no evidence of any interference from the Congo red present. The results of the titrations are given in Table XXVI, in which the second column represents the amount of Congo red taken as indicator. The third column gives the number of cubic centimeters of the hydrogen potassium sulphate solution required, and the fourth column the number of cubic centimeters of N/10 silver nitrate solution required:

Table XXVI.—*Titrations for carbonates and chlorides, when Congo red is used as an indicator.*

No.	Amount of Congo red.	Quantity of $N/20$ $HKSO_4$ required.	Quantity of $N/10$ $AgNO_3$ required.
		c. c.	*c. c.*
16	2 drops	16.8	9.95
17	1 drop	16.8	10
18	2 drops	16.8	10

With the amount of indicator used no difficulty whatever was experienced in getting sharp readings and very satisfactory determinations for the chloride present. Using large amounts of Congo red, however, more or less difficulty was experienced in determining the chlorides sharply. Apparently silver forms a compound with Congo red which gives a solution with a color very nearly that of silver chromate, so that the end reaction in the titration is more or less masked thereby. Under no circumstances, when chlorides are to be determined, is Congo red as satisfactory as methyl orange, and this latter is to be preferred when the conditions of the work in hand will admit of its use.

With potassium salts the method is quite as satisfactory as with sodium salts, and it does not seem worth while to present any figures in further demonstration of it.

A solution of magnesium carbonate in water saturated with carbon dioxide was examined. Three 10 cubic centimeter portions were titrated with the hydrogen potassium sulphate solution, using Congo red as indicator, with the following result, the figures in brackets indicating the quantity of indicator used:

19.6 [1 drop]   19.7 [2 drops]   19.6 [1 drop]

Using larger amounts of the indicator, similar results to those with the sodium carbonate were obtained—a tendency to obtain too low readings when much indicator was used. In this case also chlorides could be estimated quite readily if too much Congo red had not been used. These statements hold as well for solutions containing calcium carbonate or bicarbonate.

DIFFICULTIES IN THE PRESENCE OF CARBONATES IN THE SOLID PHASE.

It sometimes occurs in field work that the solutions obtained hold in suspension calcium or magnesium carbonate in the solid phase in a more or less finely divided condition or as a constituent of a clay. Difficulty has been experienced in the use of the method under such conditions; therefore considerable attention has been given to it in the laboratory, both with soils actually found in the field and with artificially prepared mixtures. Many attempts have been made to get around the difficulty. It was hoped that by making the titrations very rapidly approximate determinations could be made; but very unsatisfactory results were obtained, for the rates of solution of both calcium and magnesium carbonate were found to be entirely too high to permit of a satisfactory determination of the end point of a titration with either methyl orange or Congo red as the indicator. It is essential, unfortunately, that the carbonates in the solid phase be removed before making the titrations. Filtration or standing and settling of the suspended matter are serious drawbacks to the use of the method in the field. Attempts are being made to get around the difficulty, but we are not prepared at the present time to report our work in this direction.[1]

PRECAUTIONS IN THE USE OF DISTILLED WATER.

It seems worth while in this connection to call attention to the fact that if a pipette be used for drawing off the portions of the solution for titration, on no account should the contents be blown out by the mouth, for the relative proportion of normal carbonate to hydrogen carbonate may well be disturbed thereby. The distilled water used should have been boiled for some time, and the wash bottle containing it should be fitted with a blow bulb to avoid the necessity of blowing out the contents with the mouth.

ANOMALOUS BEHAVIOR OF CONGO RED.

It has been pointed out by Cohen[2] that solutions of Congo red do to some extent change color when a stream of carbon dioxide is passed through the solution. This would seem to show that Congo red is an acid weaker than carbonic acid and its use as an indicator in the presence of bicarbonates would be prohibited. This statement of Cohen was confirmed by some experiments made in this laboratory, so far as solutions in pure water are concerned; but when the solutions contained also some salt (such as sodium sulphate or sodium chloride) no effect whatever could be observed when carbon dioxide was passed in.

No explanation is apparent to account for this seemingly anomalous behavior. Experience has amply demonstrated that under the conditions involved in a titration for the estimation of bicarbonates no apparent effect on the Congo red is to be noticed from the carbonic acid dissolved in the solution, either before the titration or as it proceeds.

SUMMARY.

The following conclusions may be drawn from the facts presented:

1. Congo red is a satisfactory indicator for bicarbonates when used in the manner described.
2. Congo red does not interfere with a subsequent titration for chlorides unless present in unusually large amounts.
3. For some eyes and under certain conditions Congo red is to be preferred to methyl orange; for those who can use it, however, methyl orange seems to be the more delicate indicator.
4. It is essential to the satisfactory use of the method that during the titration the solution should not be in contact with carbonates, bicarbonates, or metallic hydroxides in the solid phase.

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[1] A description of a very efficient filter pump for laboratory or field use will shortly be published by Mr. Briggs.

[2] Indicators and Test Papers, p. 57 (1899).

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 21

MILTON WHITNEY, Chief.

RECLAMATION OF ALKALI LANDS IN EGYPT.

AS ADAPTED TO SIMILAR WORK IN THE UNITED STATES.

BY

THOS. H. MEANS.

IN CHARGE OF ALKALI LAND RECLAMATION, BUREAU OF SOILS.

In cooperation with the Office of Seed and Plant Introduction and Distribution, Bureau of Plant Industry.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1903.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., March 31, 1903.

Sir: I have the honor to transmit herewith the manuscript of a report on the reclamation of alkali lands in Egypt as adapted to similar work in the United States, by Thomas H. Means, of this Bureau. I recommend that this report be published as Bulletin No. 21 of the Bureau of Soils.

The illustrations, which comprise eight half-tone plates and six text figures, are considered essential to a clear understanding of the text.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The information given in this report was collected by Mr. Thomas H. Means during a visit to Egypt in the summer of 1902, when he was detailed from this Bureau to accompany Mr. Thomas H. Kearney, of the Bureau of Plant Industry, to northern Africa for the purpose of collecting seeds of alkali resistant plants of that region. The expenses of this journey were paid from the fund for Seed and Plant Introduction, under control of the Bureau of Plant Industry. This report is, by permission, published by the Bureau of Soils, to which this particular line of work pertains.

There is in arid America, according to the calculations of Newell, sufficient water for the irrigation of 74,000,000 acres of land, but in 1899 only 7,263,273 acres were irrigated. The field parties of the Bureau of Soils have mapped the soils and studied the alkali conditions of a number of typical irrigated districts, covering over 3,000,000 acres of land. They have found that on the average about 13 per cent of the irrigated lands examined contain alkali in sufficient quantities to be either harmful to the growth of crops or to entirely prevent profitable cultivation. If this ratio holds in the entire area of irrigable lands of the United States (and careful estimates seem to show that it does), then there are over 9,000,000 acres which contain an excess of alkali salts, or which, in the natural course of events, will develop a harmful excess of salts unless there is a radical change in the present methods of irrigation.

The value of this alkali land is nominal, the greater part of it being priced at $10 per acre or less. Were this land in a fertile condition its value under irrigation would be at least $75 per acre. If it can be brought into a state of fertility its value will therefore be increased $65 per acre; and in order that the reclamation may be a commercial success, it must be carried out at a cost below this amount.

The subject of alkali has been a source of much anxiety to our Western people, and the vast injury that has been done through the occurrence of alkali has prejudiced outsiders in irrigation enterprises to such an extent that in many communities the subject has been exceedingly unpopular, and any reference to it in connection with certain localities has been vigorously opposed and criticised.

It must be recognized that alkali occurs in all arid countries, and it is a problem for consideration and suitable control by the people of irrigated arid districts, as the suitable drainage of rice lands or corn and wheat lands has been in other parts of the humid regions.

The experts of the Bureau of Soils firmly believe that the alkali lands of this country can be economically reclaimed and that the damage from alkali is unnecessary and will not result if proper precautions are taken. Furthermore, it is a well-known fact that in most cases alkali accumulates in the most fertile soils, and the presence of alkali in the soils of arid regions should indicate to the people as a rule a high degree of fertility, provided proper methods of handling the soil are adopted.

The publications of this Bureau have been recommending drainage for the reclamation of these waste lands. This recommendation had previously been made by other writers on the subject, and all who have given this matter any thought are unanimous in the opinion that drainage will solve the problem.

As no work of reclamation by drainage has been carried on to completion in this country, it is impossible to say what the actual cost of reclamation would be, but very reasonable estimates based upon the cost of land drainage in the humid States have placed the probable cost of alkali land reclamation at from $10 to $30 per acre. In Egypt large areas have been reclaimed and are now producing crops, and from figures given by the engineers in charge of this work the cost of reclamation can be readily calculated.

The results obtained in Egypt, as will be shown in the following pages, thoroughly warrant the statements made in previous publications of this Bureau as to the practicability of reclamation by drainage, for it will be seen that the cost of reclamation is so low that much of the land of the West now lying idle on account of alkali or seepage water can be made to produce crops in from one to three years, with an expenditure much below the value of the land when reclaimed.

Placing the average cost of reclamation at $20 per acre, the profit in reclaiming an acre of land is $40, or if the 940,000 acres of alkali land now lying below existing irrigation canals are reclaimed the profit will amount to $37,000,000. If proper care is taken in the future extension of the irrigated area in the arid West, practically all of the alkali land can be reclaimed and the rise of alkali in land now fertile can be entirely prevented.

In order to gain an idea of the character of the work which is being done in Egypt, some of the most important pieces of reclamation work will be described in detail and the methods there in use will be made applicable to our own conditions.

The alkali reclamation party of the Bureau of Soils is carrying on certain work in several localities in the West to demonstrate to the people that alkali lands can be economically reclaimed. A tract of 40 acres of land, containing on the average nearly 6 per cent of alkali to a depth of 6 feet, has been taken up on the great flat between Great Salt Lake and Salt Lake City, and through the cooperation of a public-spirited individual and the Utah experiment station this land has been underdrained and was subjected to a single flooding at the end of the past season. The drains have continued to run as the result of this flooding and subsequent rains and snows, carrying off the drainage water, containing between 2 and 3 per cent of salt. It is believed that in spite of the comparatively short irrigation season of that locality, during the present year this land can be sufficiently sweetened to grow a shallow-rooted crop, and that in two years the land will be sufficiently reclaimed to grow any crop suited to the locality.

A similar demonstration is being made in the Central Colony at Fresno, Cal., on a tract of 20 acres. The drains have just been installed and the irrigation waters turned onto the land. Similar work is being started at Yakima, Wash., and it is proposed to start another demonstration work at Billings, Mont. These four places have been selected as centers at which to carry on the work under the belief that the success which it is thought will be attained at those places will be such an object lesson that the method of providing suitable drainage for irrigation lands will be generally recognized and practiced wherever conditions make it necessary.

MILTON WHITNEY.

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RECLAMATION OF ALKALI LANDS IN EGYPT.

AGRICULTURAL DEVELOPMENT OF EGYPT.

The soils of Egypt have been farmed for thousands of years. The date of the reign of the earliest of the Pharaohs is much disputed, but some authorities assert that Menes, the traditional founder of the first dynasty, lived about 5000 B. C. As the country under this dynasty seems to have been in a high state of civilization, one would naturally infer an even earlier period during which this civilization was developed. During the fifth dynasty, three or four thousand years before Christ, agriculture, as shown on tombs and monuments, had reached a state of development which was hardly exceeded until the present century. Even to-day the plow used by the fellah is the same as that pictured upon monuments of the fifth dynasty.

There are in Egypt at the present time 6,250,000 acres of irrigated land, and it is supposed that under the Pharaohs a much larger area was under cultivation, for at the present time one-third of the irrigable land is uncultivated. At the time of the Arabian conquest, in the seventh century A. D., a large portion of Egypt was devastated, the banks of the old basins were broken, and large areas were flooded with salt water or left idle. The land thus abandoned was subject to evaporation from the surface, as a consequence of which over 1,500,000 acres of land have been so damaged by the rise of salt and alkali that their cultivation is no longer possible. These lands lie in a fringe around the lower edge of the Delta, and extend from Alexandria to Suez. The greater part lies below the 3-meter (9.8 feet) contour; a great deal of that between 3 and 7 meters (9.8 and 23 feet) is charged with salt or alkali, while above 7 meters (23 feet) in elevation the land is practically free from salt.

Except for those small areas of land lying too high to be reached by the ordinary floods of the Nile, the ancients used only the basin system of irrigation. This method consists of flooding the land to a depth of from 3 to 5 feet at the season of high Nile, and of maintaining this depth of water for about six weeks, when the water is drained back into the Nile, and the seed is sown, without plowing or other cultivation, on the surface of the newly deposited mud. (See Pl. I, fig. 1.)

In this way but one crop could be grown each year. The higher lands were covered only by the highest floods, or only eight or nine times in a century. During the remaining years these lands were irrigated by lifting the water from the canals or the river. It can readily be seen that there was little opportunity for the accumulation of alkali salts so long as the basin method of irrigation was kept up, for the large amount of water which washed over and through the soil each year either removed the salts or washed them down so deep that the capillary forces were unable to return them to the surface before the next annual flood. Upon the abandonment of this method, however, the movement of soil moisture was entirely from below, and the soluble salts gradually accumulated at the surface. (See Pl. II.) Other considerable areas which lay very near or slightly below sea level were flooded with salt water from the Mediterranean. There are said to be at the present time 1,180,000 acres of land in the shallow salt lakes around the edge of the delta. Most of this land, it is believed, was under cultivation down to the time of the Roman occupation, for the ruins of ancient cities or towns are found upon mounds rising out of these shallow lakes. Moreover, Strabo and Horace sing the praises of the wines raised in the basin of what is now Lake Mareotis. It can not be definitely said, however, that the beds of these lakes were then, as now, below sea level, for the surface of the country may have sunk since that time.

When Napoleon was in Egypt in 1798 and 1799, he is said to have expressed the opinion that the time would come when a dam would be placed across the Nile at the point of division, so that water could be turned either into the Rosetta or the Damietta branch at will, thus doubling the inundation.

Mehemet Ali, who became viceroy in 1805, with his indomitable will and courage changed the method of irrigation in Egypt by cutting a number of deep canals, thus permitting the irrigation of land throughout the year. Cotton was introduced into Egypt about this time, and as this plant can not thrive where basin irrigation is practiced, its increasing importance was a prominent factor in causing the extension of perennial irrigation. The river was so low during the greater part of the year that it required pumping to supply the cotton fields. In 1833 Linant Pasha proposed to construct across the Nile at its point of division a regulating dam, which would allow the floods to pass unchecked, but which, by means of gates, would permit the water to be raised at low Nile to a sufficient height to fill canals running at such a level that irrigation could be practiced without pumping. The construction of this barrage was decreed by Mehemet Ali, but the impetuosity of the man so hastened the work that proper care was not exercised in the construction. The barrage was completed in 1865, but

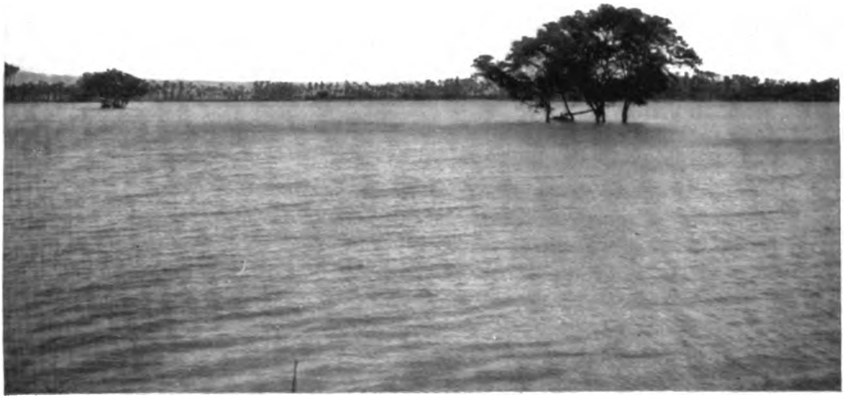


FIG. 1.—BASIN METHOD OF IRRIGATION.

Formerly all the cultivated lands were irrigated once a year by turning on from 2 to 6 feet of water, which was allowed to stand six weeks and then drained off when the flood subsided. There has never been trouble from the rise of alkali with this method of irrigation. The method did not, however, allow the growing of cotton or more than one crop in the year.

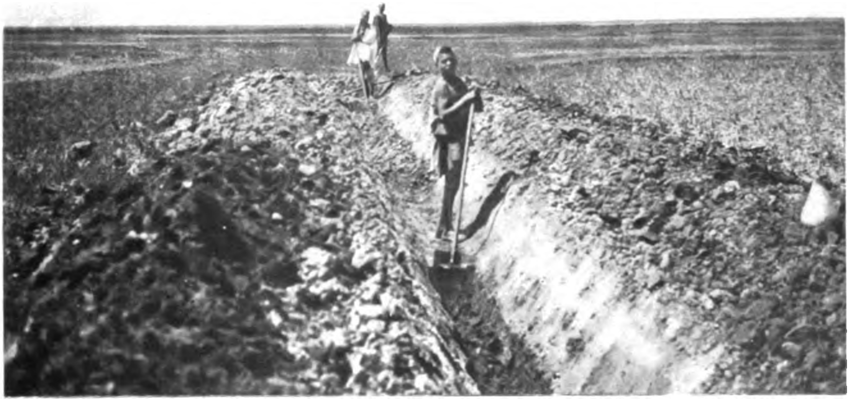
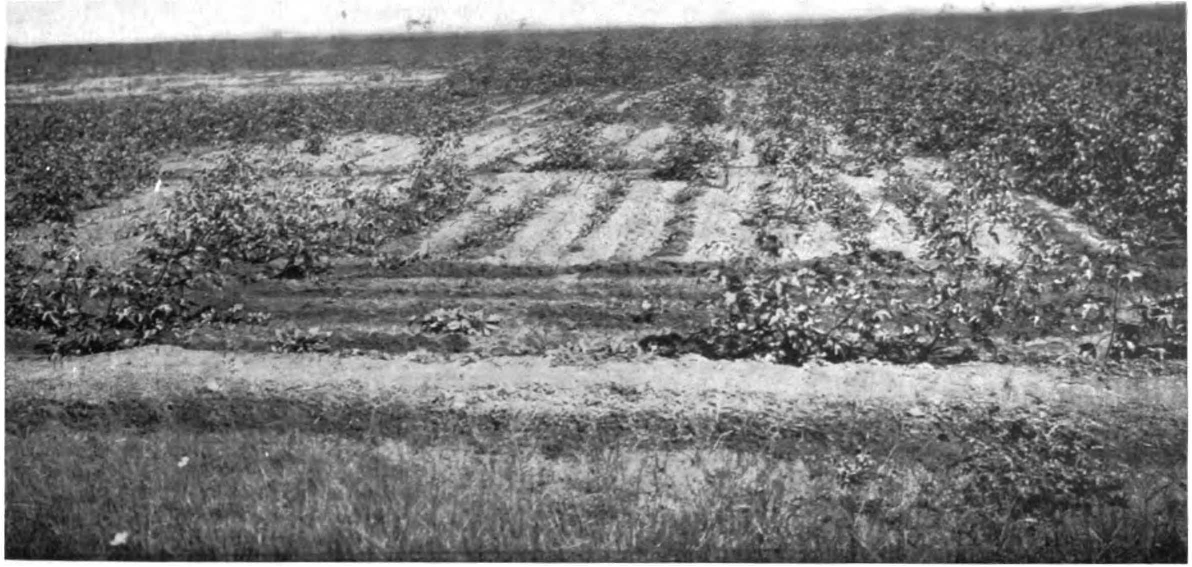


FIG. 2.—DITCHING ALKALI LAND.

The first steps in reclamation of these lands.

PLATE II.



ALKALI SPOT APPEARING IN COTTON FIELD.

Cotton can not be grown under the basin method of irrigation, as it requires frequent applications of water throughout the year. It is this change in the practice from basin to perennial irrigation for the production of two or three crops in a season—a method used commonly in the United States—which has resulted in the rise of alkali over large areas in the Nile Valley which had been successfully cultivated for thousands of years previously without damage from this source. Even where the basin method was abandoned, as, for example, after the Arabian conquest, the lands developed alkali and have been unproductive to this time.

was never entirely efficient until 1895, when the water was raised to the desired level. At the present time all of the land of lower Egypt is supplied with perennial irrigation, the greater part of the water being taken out of the Nile at this barrage.

The great advantage of the perennial over the basin method of irrigation can readily be seen. Under the basin method but one crop was possible each year, while under the perennial method two and generally three crops are produced. There is yet a great deal of land under basin irrigation in Upper Egypt, but gradually canals are being dug and the system of perennial irrigation extended. In a very few years practically all the land of Egypt will be under the improved system.

The change from basin to perennial irrigation in Egypt has not been without its misfortunes, for certain areas have been allowed to lie idle pending the completion of canal systems, and alkali has risen. Mr. Willcocks, in his first book on the Irrigation of Egypt, seems to be of the opinion that it will be necessary to return to basin irrigation in order to wash the alkali from these lands. Later practice has shown that the method best adapted to reclamation is essentially basin irrigation; but the basins are small, about 3½ acres in extent. Other writers upon this subject ascribe much of the alkali and salt land to the change in the system of irrigation, and during the transition period this was probably true; but, now that the methods of perennial irrigation are well understood and the causes of the rise of alkali better known, perennial irrigation, while more profitable, is seen to be just as safe, if proper precautions are used, as basin irrigation.

CLIMATE OF EGYPT.

The climate of Egypt is arid. Over the greater part of the country there is practically no rainfall, and in no part is there sufficient rainfall to produce crops without irrigation. The average precipitation at Alexandria is 8.26 inches. At Port Said it is 3.49 inches; at Cairo, 1.06 inches. In upper Egypt, south of Cairo, there are no observations on the amount of rainfall, so that no exact figures can be given. There is, however, less rainfall than at Cairo.

The average temperature is high. The coolest portion of Egypt lies along the coast of the Mediterranean, and the temperature increases as one proceeds south. The table on the following page gives the normal monthly and annual temperature of Alexandria and Cairo, together with normal temperatures at a number of points in the United States for comparison.

Normal monthly and annual temperature.

Month.	Alexandria, Egypt.	Cairo, Egypt.	San Antonio, Tex.	Montgomery, Ala.	Yuma, Ariz.
	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
January	58.8	55.0	51.5	48.3	54.1
February	59.4	58.5	55.8	52.7	58.8
March	62.1	63.1	61.9	57.0	64.5
April	65.8	70.3	70.1	65.4	69.8
May	70.7	75.2	74.9	72.8	77.2
June	75.6	81.0	80.7	79.4	84.9
July	80.1	84.0	83.3	81.5	91.5
August	79.9	82.4	82.2	79.8	90.7
September	76.5	77.2	77.5	75.6	84.4
October	73.2	73.9	69.7	65.2	73.0
November	68.9	65.1	59.0	55.2	61.9
December	62.6	58.3	54.9	49.6	56.0
Year	69.5	70.3	68.5	65.2	72.2

The temperature at Alexandria is normally lower than that at Cairo, and is more uniform, the winters being warmer and the summers cooler. There is probably no place in the United States where the temperature conditions correspond exactly with those in Egypt, but a careful examination of the records of the Weather Bureau reveals the fact that a zone through the southern tier of States, extending from San Antonio, Tex., eastward through Montgomery, Ala., has a normal summer temperature very close to that of Lower Egypt. It has been generally supposed that the climate of the country around the mouth of the Colorado River and extending up into the Colorado River Valley in Arizona and California is very similar to the climate of Egypt. Such, however, is not the case. Normal temperatures from Yuma, Ariz., are included in this table, from which it will be seen that there is a great difference between the temperatures of the two countries. Upper Egypt, no doubt, has a desert climate similar to that of Yuma, but meteorological records have not been kept in that part of the country.

The climate of Egypt may be described as subtropical. Slight frosts occur at Cairo and over portions of the Delta and Middle Egypt, but Upper Egypt and a portion of the Delta close to the Mediterranean Sea are said to be frostless. Oranges, date palms, and other subtropical fruits can be grown throughout the country.

Lying as Egypt does in the midst of the greatest desert area in the world, and having so light a precipitation, it has been generally supposed that the climate is that of a desert—that is to say, that the atmosphere is normally very dry. So far as can be said in the absence of continued scientific observations, Upper Egypt and a portion of Middle Egypt have a climate of this type; but the greater part of Egypt and that part in which cotton—the chief agricultural export—is grown has a climate very different from that of a desert. During the greater part of the year the prevailing wind is toward the south, blowing from the Mediterranean Sea to the land. This wind in its passage over the sea becomes charged with moisture, and thus gives to the atmosphere of Egypt a much higher relative humidity than is found in a true desert climate. The following table gives the mean monthly and annual relative humidity at two stations in Egypt and at a number of places in the United States.

Mean monthly and annual relative humidity.

Month.	Alexandria, Egypt.	Cairo, Egypt.	San Antonio, Tex.	Oklahoma, Okla.	Montgomery, Ala.	Atlanta, Ga.	Yuma, Ariz.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
January	68.0	66.4	65.6	74.5	75.3	76.4	45.4
February	67.0	60.4	63.8	73.0	74.7	73.9	43.8
March	68.0	58.0	62.1	68.3	68.8	68.6	43.0
April	69.0	52.0	67.7	65.3	64.8	62.4	35.1
May	69.0	50.1	69.6	73.0	66.8	65.9	36.7
June	72.0	50.9	67.3	73.2	70.1	71.1	34.7
July	75.0	51.8	64.0	71.3	76.0	76.3	42.8
August	73.0	57.5	65.2	68.8	78.1	77.9	47.7
September	69.0	65.0	68.8	67.8	74.0	75.2	44.7
October	68.0	68.5	63.7	64.5	69.0	68.4	46.2
November	67.0	69.5	65.3	71.0	72.7	73.3	43.3
December	68.0	71.1	62.8	74.1	75.6	75.6	51.4
Year	69.4	60.1	65.5	70.4	72.2	72.1	42.9

There is no place in the United States, so far as records are available, where the normal relative humidity is that of Cairo, Egypt, throughout the year. There are places, however, where the conditions are very close to those at Alexandria, and a large area, coinciding with the area of similar temperatures already referred to, extending from San Antonio, Tex., eastward through Montgomery, Ala., has a summer relative humidity similar to that at Alexandria and intermediate between the humidity at Alexandria and at Cairo. Ninety per cent of the cotton exported from Egypt is grown in the Delta, in a climate intermediate between that of Alexandria and Cairo, and therefore, as far as temperature and relative humidity are concerned, that portion of the United States which lies in a broad zone through central and northern Texas and central Louisiana, Mississippi, Alabama, and Georgia is the most promising territory for the growth of Egyptian cotton.

There is one point of importance regarding the climate of Egypt which is not brought out in the accompanying tables, and that is the great variability of the relative humidity from day to day. There is hardly a month in the year in Egypt, especially in the upper part of the Delta, near Cairo, when the relative daily humidity has not a range of 70 per cent, or from a very dry to a saturated atmosphere. This great range is not characteristic of the cotton belt in the United States outlined above.

The table also shows the relative humidity at Yuma, Ariz., and a glance will show that the conditions there are totally different from the conditions existing in Lower Egypt.

The mean evaporation from a water surface in Cairo and in three places in the United States is shown in the following table. So far as can be found, there is no point in America where the evaporation during the summer months is the same as that in Egypt, but a glance at the table will show that the evaporation in Cairo lies intermediate between the figures for the cotton belt and those for Yuma, Ariz. The Weather Bureau statistics upon evaporation are very irregular and admittedly not altogether reliable, and it is thought that if observations were carried on with the same kind of instruments in the two countries places of greater similarity would be found.

Comparison of mean evaporation from the water surface in Egypt and in the United States.

Month.	Cairo, Egypt.	San Antonio, Tex.	Montgomery, Ala.	Yuma, Ariz.
	Inches.	*Inches.*	*Inches.*	*Inches.*
January	2.61			
February	3.14			
March	4.92			
April	5.77	4.68	4.81	8.32
May	7.18	5.27	4.24	9.17
June	8.23	4.79	5.83	10.56
July	8.51	6.77	3.65	9.87
August	7.17	6.54	4.27	9.08
September	5.21	4.71	4.12	9.73
October	4.25			
November	2.83			
December	2.43			
Year	62.25			

PHYSIOGRAPHY AND GEOLOGY.

Egypt includes within its borders all of the northeastern part of Africa between 25° east longitude and the Red Sea, and 21° north latitude and the Mediterranean Sea, a total area of about 400,000 square miles. Of this great area only about 10,000 square miles are cultivated and thickly populated. The remainder is desert, with a scanty population and little agricultural interest.

Alexandria, Egypt, is situated on about the same parallel as Jacksonville, Fla. Cairo is on the same parallel as New Orleans, while Assuan, the southernmost town of importance in Egypt, situated at the First Cataract, is on the same parallel as Durango, Mexico, or a few miles north of Habana, Cuba.

The part of Egypt of interest to the farmers of America is confined to the valley and delta of the Nile. The valley of the Nile, or Upper Egypt, extends from the First Cataract, or Assuan, to Cairo, a distance of 550 miles. The valley has an average width of about 5 miles, varying from that up to 10 or 12 miles. It is a trough, cut through almost horizontal Cretaceous and Tertiary sandstones and limestones, in which has been deposited the sediment from the Nile. The sediment varies from 33 to 115 feet in thickness. A typical cross section of the valley shows the land immediately along the river bank to be higher than that near the bluffs which bound the valley. These front lands are only flooded during extremely high water.

The part of the country north of Cairo, the delta of the Nile, is a fan-shaped area with a radius of 125 miles, gently sloping toward the sea. Radiating toward the sea from the apex of the delta are gentle ridges which mark the position of present or ancient branches of the Nile. Around the edge of the delta is a series of salt lakes, the bottoms of which lie a few inches or a few feet below sea level. These lakes are separated from the sea by a narrow stretch of sandy beach, cut here and there by a few openings through which the tide ebbs and flows.

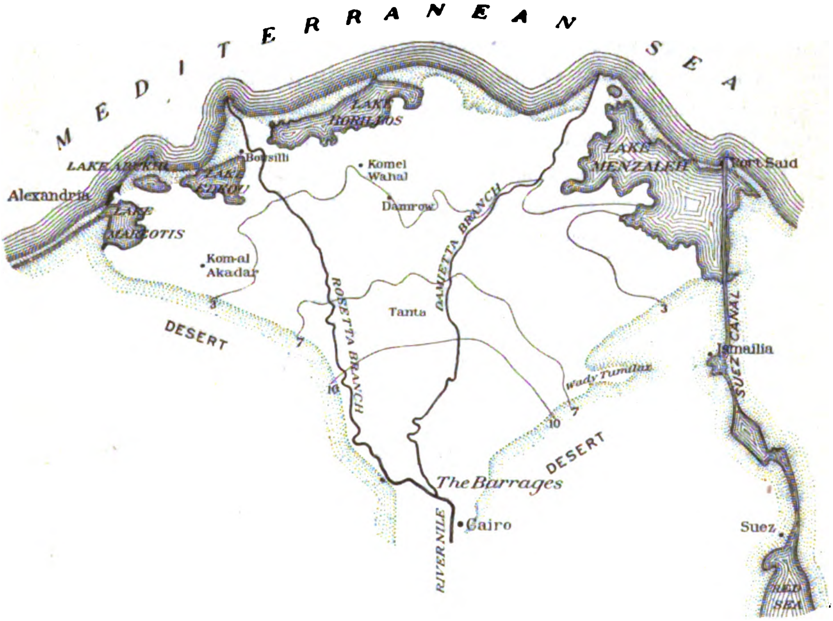


FIG. 1.—Sketch map of the Nile Delta.

The thickness of the layer of Nile mud which forms the soil of Lower Egypt, according to Captain Lyons, director-general of surveys of Egypt, varies from 40 to 60 feet.

A third physiographic province of Egypt is the Fayum, a province lying west of the Nile Valley in an oasis in the Libyan Desert. This province is an oval-shaped basin surrounded by desert hills, connected with the Nile Valley by a narrow opening in the hills bounding the valley on the west. The plateau of the Libyan Desert is at this place 300 to 400 feet above sea level. The depression in these hills slopes from the level of the Nile Valley in a northwesterly direction to Lake Karoun, the remains of the ancient Lake Moeris, which is 140 feet below sea level. The Fayum is watered by a canal, Bahr Youssef, taking water from the Nile at Assiut, and has a desert climate and a very fertile soil.

THE NILE.

The Nile rises in central Africa in a region of heavy rainfall and flows northward across a desert country. The area of the drainage basin of this great river is about 1,200,000 square miles. The two main branches are the White Nile, rising in the great lakes in central Africa, and the Blue Nile, which drains the mountains of Abyssinia.

The White Nile rises in, and flows through, a truly tropical country. The rainfall of this area is fairly high, amounting to 30 or 35 inches each year. The great lakes of central Africa lie along this stream and act as regulators of the discharge. According to Mr. Willcocks, the mean discharge of the river as it leaves Lake Victoria Nyanza is 30,000 cubic feet per second, ranging from 25,000 to 35,000 cubic feet per second during the year. Between this lake and Khartum, where the Blue Nile joins the stream, a distance of 1,620 miles, there are large areas of swamps and lagoons where the river divides and presents a large surface for evaporation.

The mean discharge of the White Nile at Khartum, below the swamps, is 60,000 cubic feet per second, with a minimum discharge of only 7,000 cubic feet and a maximum of 150,000 cubic feet per second. The difference between the minimum discharge at the outlet of Lake Victoria Nyanza and the discharge at Khartum represents the loss which takes place in traversing the great swamp regions of central Africa.

The White Nile is a clear-water stream, as the sediment which enters the stream during the rainy season either settles in the lakes or is filtered out in passing through the great areas of swamp. This swamp or "sudd" region occupies the basin of what was once a lake, but which has silted up sufficiently to permit the growth of water loving vegetation. During the season of low water, and particularly after the first rains, the discharge from these swamps is highly charged with organic matter, giving rise to the "green" water of the Nile in Egypt.

The Blue Nile drains the mountains of Abyssinia. The river has a minimum discharge of 200 or 300 cubic feet per second and a maximum discharge of nearly 300,000 cubic feet per second. The water of the stream in time of flood is very muddy and gives rise to the "red" water of the Nile—the water so much desired by the irrigator in Egypt, on account of the fertility which this mud adds to the soil.

The only other tributary of the Nile is the Atbara, a stream which enters about 200 miles below Khartum and whose characteristics are very similar to those of the Blue Nile.

The Nile at Assuan, or the First Cataract, where the stream enters Egypt proper, has a normal flow of 100,000 cubic feet per second, varying from a minimum of 7,000 to a maximum of 475,000 cubic feet per second. The rise and fall of the river is very regular, and upon the regularity and height of the rise depends the success or failure of the crops of Egypt. A very low flood, according to Mr. Willcocks, discharges but 210,000 cubic feet per second, and there is a scarcity of water for irrigation; a good flood discharges 350,000 cubic feet per second, and a dangerously high flood, or one of 450,000 cubic feet per second, causes much damage.

The annual rise commences about the 15th of June and the maximum is reached during the month of September. The river continues near its maximum for a period of from ten to thirty days and then commences to subside, reaching its minimum in May or June. The rise at Assuan averages about 35 feet and at Cairo about 25 feet.

During low water, or when the water is practically all coming from the White Nile, there is very little sediment, but during the season of high water, or when the stream is being fed from the Blue Nile, there is more or less sediment of a mineral nature.

The following table, from analyses by Mathey, shows the material in suspension and in solution throughout the year:

Analyses of Nile water by Mathey, 1887.[a]

[In parts per 100.000.]

Constituents.	Jan.-Feb.	Mar.-Apr.	May-June.	July-Aug.	Sept.-Oct.	Nov.-Dec.
In solution:						
Nitrogen, calculated as ammonia	0.016	0.015	0.017	0.056	0.021	0.019
Lime	4.21	4.32	4.27	4.17	4.67	4.64
Potash	.91	.84	2.09	1.91	1.34	1.02
Sulphuric acid	.28	.28	.31	.32	.19	.14
Organic matter	1.32	1.21	1.05	2.40	1.95	1.49
Carbonic acid	3.41	3.63	4.10	3.72	3.04	4.07
Phosphoric acid	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
In suspension	132.4	49.8	142.7	181.9	390.3	291.4

[a] See Annales de la Science Agronomique, Vol. II, p. 340.

It will be seen that the river, at the time of low water, carries but about 50 parts of sediment to 100,000 parts of water. This amount increases until in September and October there are nearly 400 parts of sediment. The analyses of the material in solution are not complete, but from other sources it seems that at low Nile the amount is greater than at high Nile. The following table gives a complete analysis of the water-soluble constituents of two samples collected at high and low Nile:

Analyses of Nile water taken at high and low Nile, respectively, by the late Dr. Letherby

[In parts per 100,000.]

Constituents.	A.	B.
Actual or saline ammonia	0.0043	0.0014
Ammonia from organic matter	.0071	.0118
Lime	4.422	5.178
Magnesia	1.033	1.029
Soda	.587	1.301
Potash	1.501	.404
Chlorine	.628	1.737
Sulphuric acid	1.837	2.931
Phosphoric acid	Tr.	Tr.
Nitric acid	Tr.	Tr.
Silica, etc	1.129	.671
Organic matter	1.186	3.129
Carbonic acid and loss	4.281	4.091
Total on evaporation	16.601	20.471
Suspended matter:		
Organic matter	18.414	.943
Mineral matter	130.743	3.829
Total suspended matter	149.157	4.772

A. Sample taken August 12, 1874, at high Nile.
B. Sample taken at Boulac May 13, 1875, at low Nile.

The above figures have been disputed, but are nevertheless given, as they may show characteristics of the Nile in an unusual season. Perhaps the most complete records made of the amount of sediment have been recently published by Dr. MacKenzie, director of the School of Agriculture at Ghizeh. The records are published in the Journal of the Khedivial Agricultural Society, vol. 1, p. 99, 1899.

Dr. MacKenzie says in part:

> As is well known, the level of the river Nile varies from month to month during the year with unfailing regularity. It is at its lowest during the months of May, June, and early July, and reaches its highest in September. * * * The suspended matter also varies from month to month and varies practically with the height of the river. When the water is at its lowest level the suspended matter is least, and when at its highest level the suspended matter is also greatest.

The table on the next page, made from diagrams published by Dr. MacKenzie, shows the amount of suspended matter in parts per 100,000 of water.

Sediment in Nile water in parts per 100,000.

Month.	1896	1897	Month.	1896	1897
January	29	49	August	100	174
February	25	27	September	166	163
March	20	19	October	135	100
April	16	14	November	90	60
May	13	14	December	63	85
June	17	13	Average	57	57
July	10	11			

Dr. MacKenzie says:

The samples of water for the determination of the suspended matter were taken from the center of the river opposite Ghizeh village. The method adopted was to take an iron tank, of about 1 meter capacity, out in a boat and fill it by means of a hand pump, taking water from 1 meter below the surface. The tank was then allowed to stand two months, after which the clear water was run off by a tap and the sediment air dried and weighed. * * * A sample of water taken at the Kosheshah escape during the discharge of the basin was found to contain 39.5 parts of suspended matter per 100,000. The 39.5 parts contained 34.8 parts of mineral matter and 4.7 parts organic matter.

The amount of suspended matter at the time of filling the basin may be taken as 170 parts per 100,000, and as 40 parts are not deposited the amount of silt left in the basin will be about 130 parts by weight for every 100,000 parts by weight of flood water in the basin.

Dr. MacKenzie calculates on this basis that about 0.04 inch is deposited each year in the basin.

The following analysis by Dr. MacKenzie shows the chemical composition of the sediment at high Nile:

	Per cent.
Insoluble matter and silica	58.17
Potash	.68
Soda	.62
Lime	3.31
Magnesia	2.42
Oxide of manganese	.09
Iron oxide and alumina	24.75
Sulphuric acid	.20
Phosphoric acid	.21
Carbonic acid	1.55
Organic matter, etc.[a]	8.00
	100.00

[a] Containing nitrogen .12

In conclusion Dr. MacKenzie states:

Nile mud does not supply a sufficient amount of nitrogen for the use of "nitrogen-consuming" crops, but the growth of berseem may, in part at least, supply this deficiency.

Nile mud supplies sufficient quantities of phosphoric acid and potash for the growth of fair crops of cotton, wheat, barley, maize, beans, and potatoes, but does not do so for sugar cane, berseem, and berseem hagazi (alfalfa), though if the two latter crops are consumed by cattle on the land they may be left out of consideration.

THE SOILS OF EGYPT.

The soils of Egypt are practically all formed from the sediment deposited by the Nile. Along the borders of the valley and close to the Mediterranean, desert sands and beach sands are mixed with the sediment, but the soils so formed occupy but a small proportion of the total surface of the land.

In the formation of alluvial soils, the most important factors governing the texture of the soil are the distance from the main channel of the river and the velocity of the water which deposits the sediment. The sediment actually in suspension in the waters of the Nile is very fine; nearly all of it would be classed as silt and clay in a mechanical analysis; but along the bottom of the channel coarser sediments are pushed and rolled, and where these bottom sands are exposed on the surface of the ground, as in and along an abandoned channel, the soils are lighter in texture. Another factor which gives rise to the formation of sands is the cementing action of lime, magnesium, iron compounds, which join together the fine grains of silt and clay and form larger aggregates, thus giving the soil a lighter appearance than a mechanical analysis would indicate. This fact has been very clearly brought out in mechanical analyses of soils from American desert lands where calcium and magnesium carbonates were abundant. In New Mexico certain soils were classed in the field as sandy loams, but upon subjecting them to mechanical analysis, where water acts upon the soil for several days, the cementing material was dissolved, the aggregates broken down, and the soil was found to contain enough clay to be classed as a loam or clay loam. The field examination of Egyptian soils shows this cementing process to be developed to a high degree, and soils in the field seem lighter than would be indicated by the mechanical analyses.

The soils of Egypt consist of fine sands, sandy loams, loams, silt loams, clay loams, and clays, grading gradually from one to the other with no sharp boundary lines. The sands and sandy loams are confined to the Nile banks and to the strips of land radiating from the point of the delta like fingers, and which mark the position of ancient arms of the Nile. There are also small areas of these lighter soils scattered here and there through the country wherever the velocity of the water which carried the sediment has been great enough to carry sands in suspension. Thus, in the basins it is common to find patches of lighter soils near the opening to the basins, and heavier soils away from these openings where the waters have flowed with less velocity.

The sandy soils are not considered so valuable as the clay loams and clays. This is in part due to the fact that the sandy areas generally lie high and suffer most in seasons of short water supply and in part to the fact that their fertility is not so lasting.

The silt loams are perhaps the soils best adapted to general farming. They are found throughout the parts of the country visited by the writer, and owe their origin to the deposition of the heavier particles of sediment carried by the floods. Such soils are easy to till, do not puddle or bake, are retentive of moisture, and are of lasting fertility.

Clay loams and clays occupy greater areas than any of the other soils of Egypt. These soils are black in color, very sticky and plastic when wet, and very hard when dry. They bake into hard clods and at times crack into irregular blocks with deep cracks 2 inches wide. The nearest prototype of this soil in America is the San Joaquin black adobe in California, but a comparison of mechanical analyses shows the soil to be very different in ultimate mechanical composition. The Sharkey clay of the Mississippi alluvial lands is similar in character, but contains much less organic matter.

A soil map of Egypt has never been made, so the exact location of the areas occupied by each type, or the relative importance of each, can not be definitely given. Should a soil survey be made and the results mapped, no doubt many facts of great interest would be developed. It would be possible to trace definitely the changes which have taken place in the Nile and its branches. Much information regarding the ancient history of the country and of the canal systems in those times would be gained, besides the inestimable present benefits to the country in the direction and assistance of the development of agriculture. Egypt is almost entirely an agricultural country—thickly settled and intensively farmed. By far the greater part of the area must be devoted to furnishing food for the people, but the remainder of the land will be devoted to crops for export. At the present time cotton is practically the only export, but in the rapid progress of all civilized countries in scientific agriculture this crop must be kept up to a very high standard, or competition of other countries may seriously curtail its markets. Some of the soils of Egypt produce a high grade type of cotton, while other soils produce an inferior grade. Our experience in our own country shows that a soil survey is the basis on which scientific direction of the development of the cotton industry, or in fact of any other important agricultural industry, can best be carried out.

The following table gives the results of mechanical analyses of samples of soils collected in Egypt:

Mechanical analyses of soils from Lower Egypt.

No.	Locality.	Description.	Organic matter.	Gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay, 0.005 to 0.0001 mm.
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
7538	Abukir tract.....	Loam, 0 to 6 inches ...	0.65	0.52	0.40	0.38	18.42	35.66	28.46	16.16
7539	.....do............	Loam, 0 to 12 inches ..	.50	.02	.08	.16	23.34	42.68	21.00	12.52
7547	Busili............	Heavy silt loam, 0 to 12 inches.	1.12	.00	.04	.04	.34	7.78	61.04	29.26
7548	.....do............	Heavy silt loam, 0 to 12 inches.	1.41	.04	.06	.02	.18	6.00	60.76	32.74
7544	Abukir tract.....	Clay loam, 0 to 12 inches.	.89	.14	.30	.18	2.32	4.14	35.08	57.44
7545	.....do............	Clay loam, 12 to 24 inches.	.69	.00	.10	.06	3.86	15.90	30.72	49.30
7546	.....do............	Clay loam, 24 to 36 inches.	1.04	.00	.04	.04	.92	5.76	51.28	41.64
7540	.....do............	Clay loam, 0 to 6 inches	.29	.46	.68	.42	6.26	8.26	31.40	51.08
7541	.....do............	Clay loam, 6 to 12 inches.	.44	.20	.28	.32	3.52	5.42	37.30	52.48
7542	.....do............	Clay loam, 0 to 6 inches	.24	.30	.42	.36	3.68	9.48	28.28	57.02
7543	.....do............	Clay loam, 6 to 12 inches.	.83	.20	.56	.24	1.76	8.74	25.76	62.62
7555	Kom-el-Akhdar..	Clay loam, 0 to 12 inches.	.45	1.84	5.80	4.20	21.94	15.84	7.48	42.10
7556	Damru...........	Clay, 0 to 12 inches....	2.46	.60	.88	.20	.58	4.98	37.08	55.46
7557	.....do............	Clay, 12 to 24 inches...	.51	1.28	.24	.26	.72	4.24	26.64	65.82
7558	.....do............	Clay, 24 to 36 inches...	.92	1.92	.58	.30	.74	3.64	24.84	67.72
7552	Kassasine........	Heavy black clay, 0 to 12 inches.	.96	.14	1.76	1.24	2.24	6.38	11.96	75.82
7553	.....do............	Heavy black clay, 12 to 24 inches.	.50	.30	1.90	.90	1.60	5.24	12.68	75.40

Mechanical analyses of soil samples from Upper Egypt.

No.	Locality.	Description.	Organic matter.	Gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay, 0.005 to 0.0001 mm.
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
7550	Fechn Station....	Sandy loam, 0 to 12 inches.	0.36	0.0	0.22	0.18	2.18	37.08	51.32	9.44
7549	.....do............	Loam, 0 to 12 inches..	.93	......	.18	.16	1.34	27.14	54.10	17.08
7551	Fant Station......	Black clay loam, 0 to 12 inches.	2.30	.24	.44	.22	.54	1.32	48.40	48.62
7554	Fechn Station....	.....do................	.90	.54	.44	.30	.98	6.56	36.40	54.16

The most of these samples were collected at points where salt-land reclamation was being carried on. They therefore may differ markedly from the best soils of Egypt in chemical composition, but it is thought they represent fairly well the mechanical composition of the soils of the country.

The percentage of the various grades of sand is low throughout the analyses, some of the soils containing excessively high percentages of clay. In this respect the analyses are misleading, for, as previously pointed out, all of the soils seem lighter in the field, due to the aggregation of particles by the cementing action of lime and magnesium carbonates. Sample 7552, according to the mechanical analysis, should be an almost impervious clay soil, but in the field this soil was found to be easily drained, perfectly amenable to cultivation, and favorable to plant growth.

A large number of chemical analyses have been made of Egyptian soils. The writer will not attempt to interpret these analyses, for many of them are very conflicting. It seems, however, that the chemical analyses bear out experience in showing that the soils of Egypt are fertile. In some cases large stores of plant food are present, awaiting the action of time to render them available for plant use, yet modern experience is daily showing that the application of fertilizers sufficiently increases the yield of crops to warrant the practice. Imported chemical fertilizers are in use, but the refuse from the ancient cities and towns and in a smaller way from modern towns forms the most important fertilizer in use.

The annual floods of the Nile, under the basin system of irrigation, left in the newly deposited sediment sufficient plant food for the one crop grown, but with the change to perennial irrigation and two or three crops each year the store of reserve plant food is being drawn on and the need of additions from outside has been seriously felt. The practice of fertilizing is becoming more necessary and more general each year, and will continue to be so with the decrease in area of basin land. Nitrogen is not abundant in the river mud, but the growing of Egyptian clover, or berseem, used regularly in rotation, largely makes up for this deficiency.

RECLAMATION OF SALT LAND AT ABUKIR.

Lake Abukir is separated from the Mediterranean by a narrow strip of sand dunes and sandy shore and is situated about 10 miles east of Alexandria. On the west and south is the basin of Lake Mareotis, and on the east Lake Edku. The bottom of Lake Abukir is from 2 to 4 feet below sea level, and before reclamation commenced it was a dry salt plain during the summer months and in winter was covered with a few inches of salt water. (See fig. 2.)

The reclamation of the land in this lake was under consideration for a long time. There were many doubts as to the feasibility of reclaiming such land at a reasonable cost, particularly among the natives of Egypt. In spite of these doubts, in 1888 the Abukir Company, Limited, was formed with capital raised in England. This company obtained a concession from the Egyptian government of about 25,000 acres of land at the bottom of this lake and immediately commenced the work of reclamation. For the first few years the success of the undertaking was doubtful, but as information regarding the best methods of reclamation was acquired greater progress was made, and at the present time one sees green fields and thrifty crops of cotton, corn, clover, and grass where once was a barren desert. The reclamation work has been a commercial success also, as is attested by the dividends of 5, 20, and 20 per cent declared by the company during the year 1902.

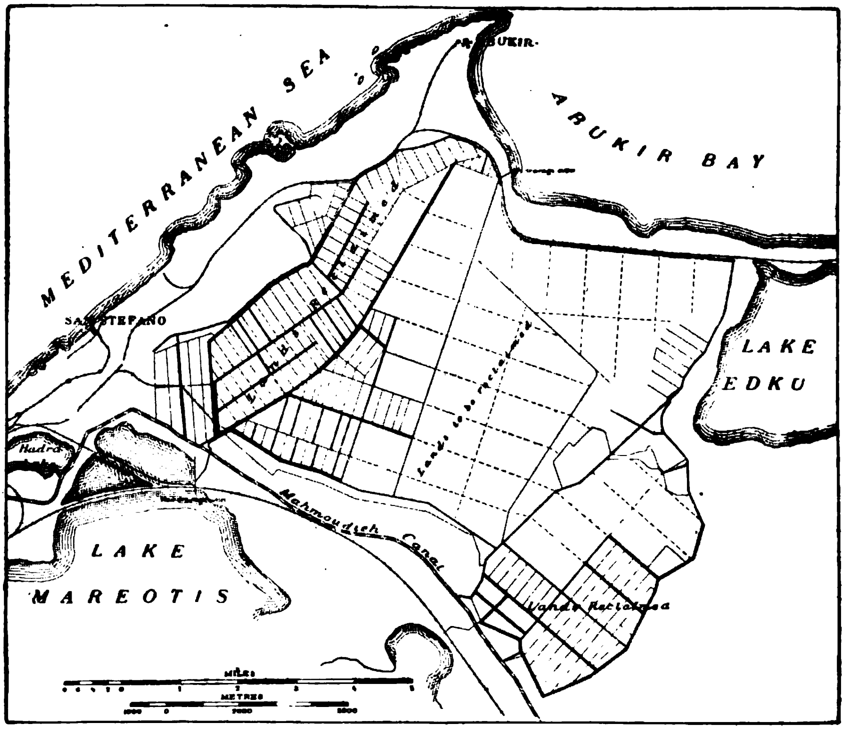


FIG. 2.—Sketch map of Abukir tract.

A part of the original bottom of the lake is yet untouched. The surface is almost level and entirely devoid of vegetation. Samples of this soil were collected by Dr. Volcker before reclamation was attempted. Samples 1 and 2 represent the average character of about 25,000 acres of the lake bottom and contain, respectively, 8.11 per cent and 8.56 per cent of sodium chloride. Sample No. 4 is an average upland soil near by, similar in character to the lake-bottom soil, but containing only 0.01 per cent sodium chloride. This soil is now producing crops each year and is rented for about $25 per acre per year. Attention is called to the high percentage of sodium chloride which the lake soil contains, sufficient to preclude any possibility of profitable agriculture. Analyses by Dr. Volcker of the sample just cited, excluding materials readily soluble in water, are given in the following table:

Analyses of soil from Lake Abukir.

Constituent.	Sample No. 1.	Sample No. 2.	Sample No. 4.
	Per cent.	*Per cent.*	*Per cent.*
Insoluble silicates and sand	66.23	45.81	54.27
Alumina	6.36	10.88	11.95
Oxide of iron	11.69	11.04	11.71
Iron pyrites	.08	.11	.10
Lime	2.08	7.73	8.03
Magnesia	1.79	.93	.50
Soda	.79	....	.41
Potash	.65	1.23	.67
Sulphuric acid	2.23	2.56	.14
Carbonic acid	.19	4.75	5.59
Phosphoric acid	.16	.19	.38
Organic matter[a]	3.64	6.21	6.24

[a] Sample No. 1 contained 0.035 per cent, sample No. 2, 0.07 per cent, and sample No. 4, 0.096 per cent of nitrogen.

In August, 1902, the writer collected a series of samples of this soil upon the unreclaimed lake bottom. Analyses of these samples (Nos. 7544, 7545, and 7546) made by Breazeale in the laboratory of the Bureau of Soils are shown in the following table:

Analyses of soils from Lake Abukir.

Constituent.	7544, 0 to 12 inches.	7545, 12 to 24 inches.	7546, 24 to 36 inches.	7538, 0 to 6 inches.	7539, 0 to 12 inches.	7540, 0 to 6 inches.	7541, 6 to 12 inches.	7542, 0 to 6 inches.	7543, 6 to 12 inches.
Ions:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Calcium (Ca)	15.45	2.68	1.44	13.46	10.12	17.18	9.72	9.16	0.0
Magnesium (Mg)	Tr.	Tr.	Tr.	Tr.	3.73	Tr.	11.87	Tr.	Tr.
Sodium (Na)	17.63	33.18	34.62	15.35	15.17	7.73	6.37	18.34	27.91
Potassium (K)	1.65	2.48	2.61	4.82	4.61	8.24	3.59	5.89	6.09
Sulphuric acid (SO_4)	34.65	12.32	8.78	46.54	32.97	53.62	7.98	41.27	44.58
Chlorine (Cl)	30.06	48.41	50.79	14.17	30.11	6.01	57.51	12.24	7.58
Bicarbonic acid (HCO_3)	.56	.93	1.86	5.66	3.29	7.22	2.96	13.10	13.84
Conventional combinations:									
Calcium sulphate ($CaSO_4$)	49.10	9.12	4.89	45.68	34.30	58.25	11.29	31.00	......
Calcium chloride ($CaCl_2$)	2.77	......	......	......	......	......	17.76	......	......
Magnesium sulphate ($MgSO_4$)	......	......	......	......	10.98	......	......	......	......
Magnesium chloride ($MgCl_2$)	......	......	......	......	5.93	......	46.54	......	......
Potassium chloride (KCl)	3.13	4.72	4.96	9.23	8.79	12.54	6.86	11.14	11.52
Potassium bicarbonate ($KHCO_3$)	......	......	......	......	......	4.30	......	......	......
Sodium chloride ($NaCl$)	44.23	76.18	79.71	16.17	35.50	......	13.57	11.36	3.52
Sodium sulphate (Na_2SO_4)	......	8.70	7.89	21.13	......	18.56	......	28.60	65.98
Sodium bicarbonate ($NaHCO_3$)	.77	1.28	2.55	7.79	4.50	6.35	3.98	17.90	18.98
Per cent soluble	10.54	9.01	5.80	1.69	1.82	1.16	4.11	.92	1.47

The average percentage of soluble matter in the surface 3 feet of soil is about 8.5. Of this a portion is calcium sulphate, or gypsum, a mineral but slightly soluble in water and more beneficial than harmful in the soil. If the percentage of calcium sulphate is deducted from the average, the percentage of soluble salts to a depth of 3 feet is 6.3, or about 380 tons per acre to that depth.

The soil of the lake bottoms is typically a heavy, dense, sticky black clay, apparently very impervious to water and one which would be difficult to underdrain. In fact, the whole aspect of the land is one of utter hopelessness, and none but the most sanguine of agricultural engineers would have undertaken its reclamation. There are, however, in the lake bottom areas of lighter soil which are easier of reclamation but are not so fertile after the reclamation has been effected.

The greater part of the lake bed is underlain by a sand similar in character to the beach sand immediately to the north.

The table on page 25 shows the mechanical analyses of samples of soil collected from this lake bed.

CONSTRUCTION OF CANALS AND DRAINAGE DITCHES.

The first step toward reclamation is the construction of canals for irrigation and of ditches for underdrainage. Irrigation water is taken from the Mamoudieh Canal by a large canal which subdivides and ramifies over the entire area to be irrigated. The main drain discharges into Lake Mareotis through a siphon under the Mamoudieh Canal. The water from Lake Mareotis is pumped into the Mediterranean by a large plant operated by the Egyptian government at Mex, about 10 miles southwest of Alexandria. This pumping plant maintains the level of the water in Lake Mareotis at about 8.2 feet (2½ meters) below sea level. The original plan for the drainage of Lake Abukir provided for a pumping station on the coast, at the old outlet of the lake on the north, but this station has now been abandoned. (See fig. 2.)

The accompanying plans show two methods of placing the canals and drains, both of which are in general use.

By the first plan (fig. 3) the secondary drains run halfway between the secondary canals and into them the tertiary drains, or laterals, run from each side. These tertiary ditches are 150 meters (492 feet) long, 80 centimeters (31½ inches) deep, 25 centimeters (9.8 inches) wide at the bottom, and 125 centimeters (49 inches) wide at the top. The distance between the drains is 50 meters (164 feet). These lateral drains subdivide the land into areas 150 by 50 meters (492 by 164 feet), containing about 1.83 acres. This tract is called a "gata," and is the unit used in renting the land.

The second plan (fig. 4) shows the system of canals and drains in use in other parts of the reclamation work. The main difference between this and the first plan is that the secondary drains run beside the secondary canals and serve as infiltration drains to catch the water which seeps from these canals, and the tertiary drains are 300 meters (984 feet) long, or twice the length of the drains in the first plan. It will be seen that in this plan a smaller amount of ditching is necessary, and where the land has the requisite fall to permit the use of such long drains this system is to be recommended.

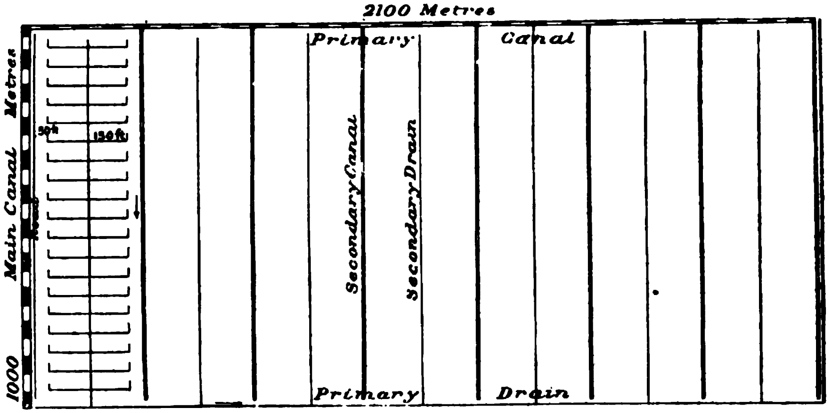


Fig. 3.—Plan of canals and drains, Abukir tract, where secondary drains are midway between secondary canals.

The land is so nearly level that very little fall can be given the canals and drains. The main drains and canals have a fall of 1 in 20,000, or about 3¼ inches to the mile; the laterals and sublaterals are

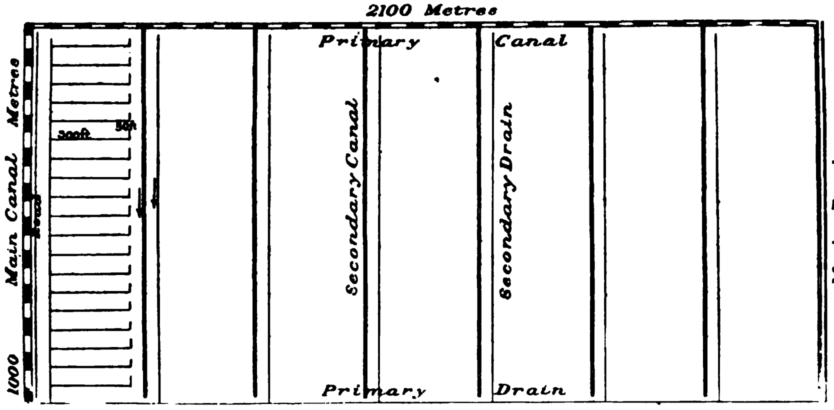


Fig. 4.—Plan of canals and drains, Abukir tract, where secondary drains are beside secondary canals.

almost level. The cost of this canalization amounts to about $12.50 per acre. This includes not only the cost of construction of canals and ditches, but also expenditures for pumping plant and the general expenses of the company, such as buildings, machinery, superintendence during construction of the works, etc.

LEVELING THE LAND.

One of the most essential parts of the reclamation system is the leveling of the land so that each field or "gata" will be perfectly level, and when flooded uniformly covered. There are two methods of leveling in use at Abukir. The first method is to use scrapers drawn by bullocks or buffaloes. These scrapers are very similar to the common scoop scraper in use in this country, but are of wood braced and protected by iron bands and with an iron cutting edge. Work with these is slow and laborious, but where labor is as cheap as in Egypt, and where it is so difficult to teach the natives to handle improved machinery, these homemade scrapers have proved very successful.

The second method of leveling is that of leveling under water by drawing a long board, on which the driver stands, across the field while it is flooded with water to a depth of 3 or 4 inches. This method is cheaper than the first method, but can not be used the first year the land is flooded, because the soil is then very soft and boggy.

FLOODING THE LAND.

After the canals and drains are dug and the land is sufficiently level to permit uniform flooding, water is turned into each gata to a depth of 4 inches. When possible this depth is maintained until the land is ready for a crop, but during the season of low water in the Nile the use of water for reclamation purposes is not permitted, so that there are times during the year when this land has to remain dry.

During the time the water remains upon the land the salt which the soil contains is dissolved and carried away by the drainage water. The drainage water is very salt and is said to contain at times over 10 per cent of sodium chloride.

On some of the land one season's washing is sufficient, but as a rule the land is washed two years before the soil is sweetened sufficiently to permit crop growth. If the first season's washing has not sufficiently sweetened the land, it is plowed during the summer months, when water is not abundant, in order to reduce the surface evaporation to a minimum.

At the end of the second year the land is usually sufficiently sweetened for some crop. Samples of the soil are examined for the percentage of sodium chloride content, as experience has shown that this is an indicator of the condition of the land as regards crop growth. The first crop to be grown is barnyard grass (*Panicum crus-galli*), called by the natives "dineba." The seed of this plant is obtained from the screenings from the rice mills, and as it is a by-product it is very cheap. If the growth of this grass is good, the soil is considered in a condition for the introduction of other crops, and as a rule Egyptian clover is then planted. While these crops are on the ground the land is heavily flooded, as much water being used as the plants will stand, so that there is no opportunity for the alkali that has been washed down to return to the surface.

The "dineba" is planted upon the flooded land, and the crop generally remains upon the ground for six weeks or two months. It is then either pastured by sheep or stock or is cut by hand and fed green. As the land sweetens salt weeds and bushes begin to grow vigorously, so that it is necessary, after cutting the "dineba," to go over the fields and clear them of this brush. The land is then flooded and sometimes harrowed, and as the water soaks away Egyptian clover seed is sown upon the wet surface. Clover occupies the ground during the fall and early winter months, and if its growth is satisfactory cotton is planted the following winter. When cotton can be successfully grown the land is considered to be fully reclaimed. This rotation is the one in general use, but at times other crops, such as corn and sorghum, are introduced.

In order to determine the percentage of salt which these crops will withstand, a number of borings were made and the samples examined. It was found that, on the average, "dineba," or barnyard grass, will not withstand more than 0.6 per cent of soluble matter in the first foot of soil. Egyptian clover requires the first foot to be even freer of salt, while Egyptian cotton has been found growing in soil that has as high as 1 per cent of salt in the surface foot. Mr. Lang Anderson, manager of the Abukir work, says:

> With 2 per cent of salt in the soil a fair crop of dineba can be grown. With 1 per cent it attains its full height. For berseem, or Egyptian clover, the percentage of salt should not exceed 0.5 per cent, and about the same for "sabini" rice.

The difference between these figures and those obtained by the writer is probably due to the fact that Mr. Anderson collected his samples to a greater depth and included some of the subsoil still charged with salt.

From all the information which could be gathered it seems that the value of barnyard grass and Egyptian clover as reclamation crops is not due to the fact that they are able to withstand a large amount of salt, but to the fact that they are very shallow rooted, growing in the immediate surface soil which has been washed free from salt, and are adapted to a very wet soil. Egyptian cotton, however, is a deep-rooted crop, its roots growing down into the subsoil, which is still charged with salt. Therefore the Egyptian cotton is actually more resistant to salt than the other two reclamation crops, though the best grades of cotton are not produced on salt lands.

The total cost of this reclamation work is given as $18.30 per acre, but it varies from this amount up to $25 or $30 per acre. This latter amount, however, includes the cost of the original purchase of the land, cost of live stock, tools, buildings, taxes, water distribution, management, seed, harvesting, and all expenses incident to the work. It will be seen that the greater part of these expenses would be incurred in taking up new land anywhere, and should not be included in the cost of actual reclamation from salt. It is very difficult to obtain figures as to the actual cost of ditching, washing, and farming until the land can be made to pay expenses and a reasonable interest on the capital invested, but it is thought that this figure does not exceed $15 per acre.

It should be remembered that the cost of labor in Egypt is very low. The ordinary farm laborer receives $5 per month, and labor by the day is paid 10 or 15 cents. Women and children take part in the minor field operations and receive from 3 to 5 cents a day. Such labor is, however, not as efficient as American labor, and the difference in cost is not so great when this fact is considered. The engineers in charge of the Abukir reclamation estimate the cost of digging the lateral ditches at 3 cents per cubic yard, a figure much below that for similar work under American conditions; but where tile are used our ditching can be done as cheaply, for ditches for tile are not dug so wide as open ditches and our workmen are more efficient.

Thoroughly reclaimed land is worth from $200 to $300 per acre, the latter price having been refused for a large tract recently reclaimed at Abukir. Much of the newly reclaimed land is being rented to individual farmers at from $10 to $30 per acre per year, depending upon the state of the reclamation.

RECLAMATION OF ALKALI LAND IN WADY TUMILAT.

Wady Tumilat is a shallow depression in the desert hills to the northeast of Cairo, and is separated from the Delta proper by a triangular area of sand hills. This depression probably at one time was occupied by an arm of the Nile, but in historic times the only water channel known was a canal from the Nile to the Red Sea, built by one of the Pharaohs about the fourteenth century before Christ. The wady is a part of what was probably the Land of Goshen, assigned to the Israelites during their stay in Egypt.

Fig. 5, reduced from a map kindly furnished by Mr. J. Langley, inspector of irrigation, who has had the direction of the reclamation work, shows the lowest part of the wady at a point where it is cut across by a line of sand hills. At this point is located the pumping station, which raises the drainage water into a canal high enough to cross the dunes. The areas inclosed by dotted lines were under cultivation before reclamation work was undertaken. As late as 1858 all the area of the wady was under cultivation. In that year the Sweetwater or Ismailia Canal was dug from the Nile near Cairo to supply the towns and workmen along the Suez Canal. This canal follows the northern margin of the wady, its bed being excavated in the sands and gravels of the edge of the desert hills. The surface of the wady is covered with a deposit of Nile mud from 2 to 8 feet deep, but underlying this heavy soil is the same sand and gravel as is found in the canal and hills on each side.

The canal loses much water by seepage through the porous bed. The water passes downward into the sands and flows laterally under the wady and to the surface in the lower parts. The water carries in solution only moderate quantities of soluble matter, but the evaporation of this water from the surface of the soil has given rise to an excess of soluble salts great enough to prevent profitable agriculture on much of the land. In 1897 probably 50 per cent of the area was out of cultivation. Much of it was under water part of the year and was a favorite resort for duck and snipe hunters. Other parts were covered with a heavy coating of salt or alkali. In that year Mr. J. Langley, inspector of irrigation, first circle, was placed in charge of the reclamation of the wady, and steps were at once taken to bring the swampy and alkaline lands again under cultivation. The system of drainage adopted is very similar to that in use in the reclamation work at Abukir, but there are several modifications to fit the local conditions.

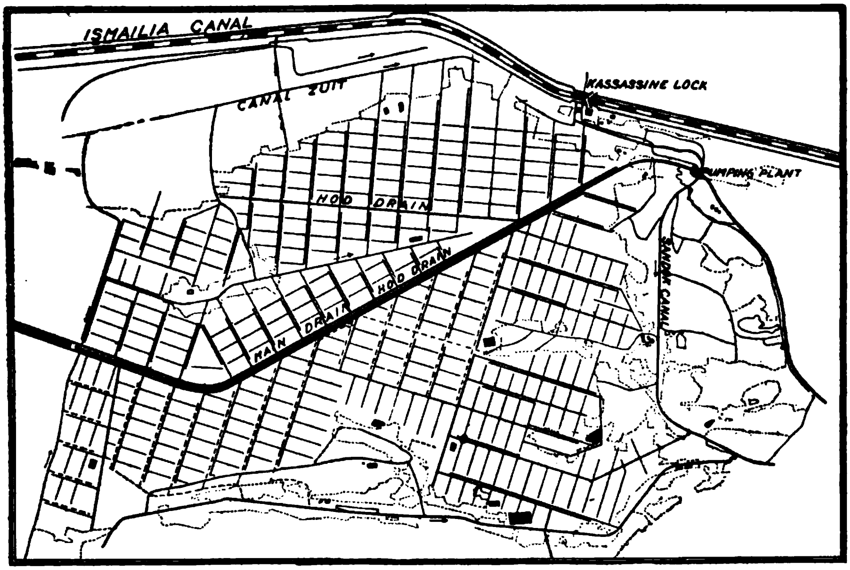


FIG. 5.—Sketch map of the east end of Wady Tumilat.

The accompanying sketch (fig. 5) shows the plan of drains and canals over the eastern portion of the wady. The distance between the laterals or tertiary drains is 100 meters (328 feet) by 250 meters (820 feet). The depth is 80 centimeters (31.4 inches). In better ground the distance is 150 meters (492 feet) by 250 meters (820 feet). These tertiary drains end in secondary drains of adequate capacity. In these and in all larger drains the aim is to keep the water surface in the ditch at least 1 meter below the surface of the soil. The main drain is 40 feet wide at the bottom, with a fall of 1 in 20,000, or 5 centimeters per kilometer (3.1 inches per mile). The upper portions of this main drain consist of two 20-foot drains side by side. This arrangement is to permit the cleaning of one while the other is being used.

The water from the main drain is lifted almost 2 meters (6.6 feet) in order to carry it over a series of sand hills between the wady proper and the salt lakes lying along the Suez Canal. This pumping plant, the location of which is shown on the map, consists of two 30-inch centrifugal pumps and one 20-inch pump, run by direct-connected double-expansion engines. The total capacity of the pumping plant is about 2½ cubic meters (88 cubic feet) per second. The area drained comprises about 18,400 acres, so that if the plant works at its maximum capacity it can remove 0.11 inch of water from the wady in twenty-four hours, or about 174½ acre-feet of water. The estimated expense of the pumping plant is $20,000 per year, which makes the cost of lifting 1 acre-foot 6½ feet 31 cents, or 4.8 cents per acre-foot per foot of lift.

The water to be pumped is not only derived from underdrainage, but also to a large extent from surface drainage and waste from the canals. At the present time, when much land is being washed and rice and samar are extensively grown, the amount of water to be drained away is great, but when the reclamation is completed and a larger area is in cotton and more attention is given to reducing the waste the quantity of water to be lifted will be greatly diminished.

At one time one important source of seepage water was the lateral canals running across the wady from the main canal on the north to the southern limits of the area. These laterals running through the lowest portion of the wady on elevated ridges or terrepleins cut off all surface drainage, and by their high level contributed much toward the accumulation of seepage water below. An important aid in reclamation was a change in this canal system, by which lateral canals were replaced by canals running along the south side of the wady, having parallel infiltration drains, or seepage drains as they would be called in America. These have proved of great use in certain cases in catching water which would subirrigate land lower down. In the case of the Wady Tumilat, however, the substratum is so porous that the infiltration drains are of little use, as the water runs beneath them and appears lower down. Another feature of great assistance in the reclamation is the Nile mud in the Ismailia Canal. This mud has so thoroughly choked up the pores of the underlying sand that the loss by seepage is now quite small.

As soon as drains and canals are dug the land is rented to natives at a nominal figure, usually $1.25 per acre per year. This rent is increased to $2.50 the second year and $3.75 the third year. At the end of the third year a new valuation of the land is made and the rental greatly increased.

The soil of the wady is typically a dense black clay, deposited by the Nile floods. A mechanical analysis is given on page 22. When dry the soil cracks much as does the San Joaquin black adobe of California; when wet it is sticky and dense and puddles easily. Underlying this heavy soil is a subsoil of sand, sandy loam, or gravelly sand. The depth to this porous substratum varies from 1 foot to 6 or 8 feet. The higher portions of the land possess a lighter soil, for here the sand of the desert hills on each side is mixed with the Nile mud.

The mechanical analysis which appears on page 22 is from an average sample of the heavy black clay. The soil contains an abnormally high percentage of clay, but seems to be a lighter soil in the field than the analysis indicates.

The character of the alkali which damages these soils is shown in the table following:

Chemical analyses of soils from Wady Tumilat.

Constituent.	7561. 0 to ½ inch.	7552. 0 to 12 inches.	7553. 12 to 24 inches.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	0.18	1.65	4.47
Magnesium (Mg)	.02	Trace.	Trace.
Sodium (Na)	35.22	24.12	19.49
Potassium (K)	1.38	6.97	7.98
Sulphuric acid (SO_4)	25.12	19.38	5.11
Chlorine (Cl)	23.41	9.94	11.19
Bicarbonic acid (HCO_3)	4.35	37.94	51.76
Carbonic acid (CO_3)	8.67	....	....
Nitric acid (NO_3)	1.39	....	....
Phosphoric acid (PO_4)	.26	....	....
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	.63	5.55	7.03
Calcium chloride ($CaCl_2$)	....	....	7.03
Sodium chloride (NaCl)	36.53	6.02	....
Potassium chloride (KCl)	2.64	13.23	14.69
Sodium sulphate (Na_2SO_4)	36.43	22.93	....
Magnesium sulphate ($MgSO_4$)	.08	....	....
Sodium bicarbonate ($NaHCO_3$)	5.99	52.27	71.25
Sodium carbonate (Na_2CO_3)	15.34	....	....
Sodium phosphate (Na_3PO_4)	.45	....	....
Sodium nitrate ($NaNO_3$)	1.91	....	....
Per cent soluble	44.51	1.69	.63

Sample No. 7552, with its subsoil, No. 7553, was collected near kilometer 7, on the main drain. It is the sample for which the mechanical analysis is given in a preceding table. Sample No. 7561 was collected near kilometer 8 and represents the character of the alkali crust in one of the spots found so difficult to wash free from alkali. The most prominent characteristic of the alkali analyses is the presence of a large quantity of soluble bicarbonates which, in the crust, where drying and aeration have taken place, have partly reverted to the carbonates. The sodium carbonate is black alkali, found here only in small spots of less than an acre in extent, though one would expect a much wider distribution when the relatively high proportion of the bicarbonates so generally present is noted.

CROPS GROWN DURING RECLAMATION.[a]

Crops are generally planted the first year of reclamation. In soils where the alkali content is high, it is necessary to wash the land six months or a year. The first crop planted is samar (*Cyperus laevigatus*), a rush used for mat making. (See Pl. III, fig. 2.) This plant is set out at intervals of 18 inches and is kept constantly under water, much as rice is grown. It has an advantage over rice in that it can go without water for a period of ten or twenty days and suffer no damage. Where the land is very salty a poor stand and yield is often the result, but almost invariably the plant yields enough to be profitable, and where good yields are secured the product is worth from $50 to $75 per acre. As stated, in nearly every case a profitable crop of samar is obtained the first year. On the worse land, however, it has sometimes been necessary to wash the soil a full year before a crop could be grown. This is particularly true of those spots which contain sodium carbonate or black alkali.

After a crop of samar has been grown, the land is in much better condition and various crops are then planted, according to the taste of the cultivator. Rotations have been adopted for use during the reclamation, of which the following have proven useful and successful:

First. Where the land is strongly alkaline: 1, washing; 2, samar; 3, cotton. The growth of the cotton indicates the extent to which the reclamation has gone. If a good stand is had and a yield of good fiber is obtained, a new rotation is planned to suit the farmer's taste. If cotton does not do well, the land goes again into samar and receives a further washing.

Second. In land which contains an average amount of alkali: 1, samar; 2, rice; 3, cotton; or, 1, rice; 2, samar; 3, cotton.

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[a] For a fuller discussion of this subject see article on Crops used in the Reclamation of Alkali Lands in Egypt, by Kearney and Means, Yearbook Dept. Agr., 1902, p. 573.

Third. In land which does not contain a large excess of soluble salts, cotton comes earlier in the rotation and is followed by less resistant crops, as: 1, samar; 2, cotton; 3, corn. For a number of years after the reclamation has gone on, it will be found advantageous to grow either rice or samar every three or four years, in order to wash from the soil the alkali which has risen above the drains.

COST OF RECLAMATION.

There are 18,400 acres of land in the wady. Upon this £E.45,000[a] ($225,000) have been spent since 1899, and before that time probably £E.27,000 ($135,000) had been spent, making a total of £E.72,000 ($360,000), or at the rate of $19.56 per acre. This total sum includes all expenses of remodeling canals, digging drains, and installing pumping station, and all operating and maintenance expenses.

Between 1881 and 1889 the average rental of the land was £E.15,047 ($75,235), with a maximum during those years of £E.20,587 ($102,925). In 1902 the rental was £E.22,000 ($110,000), and it is estimated that the rental for 1903 will be £E.26,500 ($132,500), or an increase of £E.10,750 ($53,750) brought about in five years by the use of $225,000. It is estimated that when the wady is thoroughly reclaimed the yearly rental will be £E.35,000 ($175,000), or almost two and one-third times its rental previous to the commencement of systematic reclamation.

The cost of ditching per cubic yard can be calculated from the following contract prices for carrying on the work:

Main canals	$0.06½
Main drains	.10⅓
Primary drains	.04½
Secondary and tertiary drains	.03⅕

One of the greatest obstacles to more rapid reclamation has been the lack of population. With the deterioration of these lands the fellahs left the wady, and the repeopling of the villages is slow. For a time the fellahs had little faith in alkali-land reclamation, but gradually the success of the method of reclamation became evident, and now settlers are easier to obtain.

RECLAMATION WORK AT DAMRU.

One of the most interesting, and what will, it is thought, be one of the most valuable experiments in reclamation of salt lands, is that being carried on by M. A. Souter, engineer in chief of the state domain, near Damru. The experiments were started in September, 1902, and the writer visited the property in October, so that nothing can be said at this time of the final results of the experiments. A plan of M. Souter's work is shown in fig. 6.

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[a] The pound Egyptian, usually written "£E.", is valued at 6½d. more than the pound sterling.

These experiments were planned to show the relative efficiency and cost of the three most important methods of reclamation in use in Egypt, namely: 1, colmatage or warping; 2, open drains; 3, tile drains.

Each of these methods is being tried on about 30 acres of land. On the first area there are no drains except those around the outside of the field, which are designed more as surface drains than as underdrains. Muddy water from the Nile is run on this land, allowed to settle, and then drained off. Then more water is run on and the process repeated. In this way large quantities of water are run over the surface of the soil and a coating of mud is deposited. (See Pl. IV.)

On the second plot open drains are being tried. These drains are 75 cm. (29.5 inches) deep and 330 meters (1,082 feet) long, the distance between them being 35 meters (115 feet). This system compares with the majority of the reclamation schemes seen in Egypt, such as those at Abukir, Wady Tumilat, Kom-el-Akhdar, and Kom-el-Wahal. M. Souter places the cost of the installation of this work at from $10 to $15 per acre. (See Pl. I, fig. 2.)

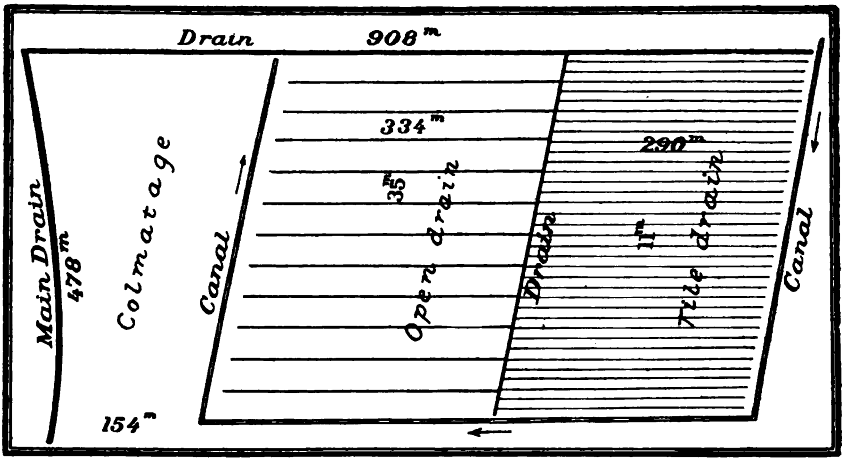


FIG. 6.—Plan of drainage experiment at Damru.

In the third field tile drains have been installed. Since good tile is not procurable in Egypt, M. Souter imported 12 cm. (4¾ inches) tile, in lengths of 50 cm. (20 inches), from Marseille, France. The tile are placed 11 meters (36 feet) apart, at an average depth of 75 cm. (29.5 inches). The tile drains are 250 meters (820 feet) long and have a fall of 6 in 10,000, or about three-fourths of an inch per 100 feet. M. Souter places the cost of this work at $30 per acre.

When visited the land had been under water fourteen days. All the drains were running full of water, and the water from the field under

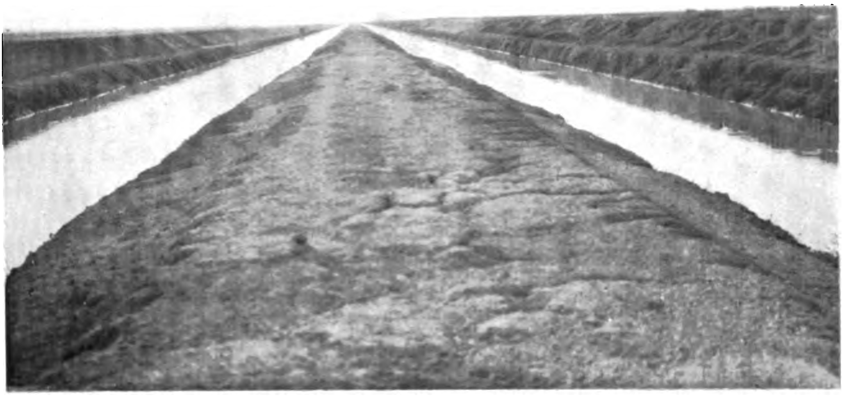


FIG. 1.—MAIN DRAINAGE DITCH IN WADY TUMILAT, USED IN MODERN METHODS OF RECLAMATION.

These ditches are run parallel, so that one may be emptied for cleaning while the other carries the drainage waters.

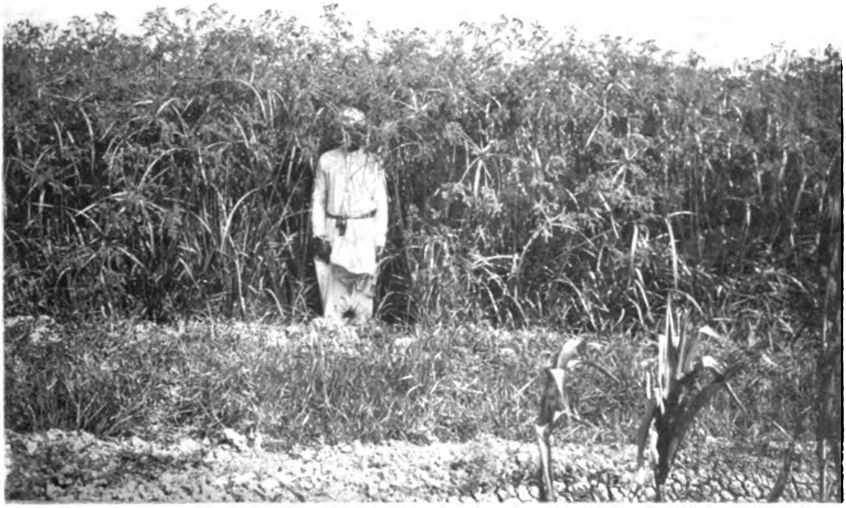


FIG. 2.—SAMAR, A SHALLOW-ROOTED CROP, ON ALKALI LAND.

The alkali is being washed from the soil by flooding while the crop is growing. Samar is used for making mats and rugs.

PLATE IV.

FLOODING LAND IN RECLAMATION WORK.

After the alkali lands are leveled and properly ditched for draining, water is turned onto the lands properly checked into small fields, to a depth of 4 inches and maintained for several months, the drainage ditches carrying off the seepage water and salt.

colmatage was running off very clear. The water was all distinctly saline to the taste, and large quantities of salt were being removed. M. Souter sampled the first water coming from the drains and found that it contained 2.5 per cent of sodium chloride.

The tile drains were running full and together were discharging about 1 cubic foot per second. At this rate 2.8 tons of salt were being removed per hour, and as the analyses given below show the average salt content to a depth of 3 feet to be 5 per cent, the drains will have removed all of the salt in one hundred and thirty-three days. This is certainly a much more rapid rate than has been attained in any other piece of reclamation work; but M. Souter's tile are placed very close together and for that reason their efficiency should be high.

The chemical composition of three samples of soil collected in 1-foot sections to a depth of 3 feet is shown in the following table:

Chemical analyses of soil from Damru.

Constituent.	7556, 0 to 12 inches.	7557, 12 to 24 inches.	7558, 24 to 36 inches.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	3.43	3.10	3.71
Magnesium (Mg)	1.60	1.61	1.61
Sodium (Na)	29.12	30.09	28.90
Potassium (K)	4.27	3.64	2.53
Sulphuric acid (SO_4)	6.05	5.19	17.06
Chlorine (Cl)	53.89	55.59	44.60
Bicarbonic acid (HCO_3)	1.64	.78	1.59
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	8.65	7.33	12.59
Magnesium sulphate ($MgSO_4$)	....	....	8.00
Sodium sulphate (Na_2SO_4)	....	....	2.62
Calcium chloride ($CaCl_2$)	2.25	2.66	....
Magnesium chloride ($MgCl_2$)	6.29	6.33	....
Potassium chloride (KCl)	8.13	6.93	4.80
Sodium chloride (NaCl)	72.43	75.71	69.85
Sodium bicarbonate ($NaHCO_3$)	2.25	1.04	2.14
Per cent soluble	5.85	4.58	4.57

It is thought that this set of samples is typical of the large area of alkali and salt land being reclaimed in Lower Egypt. A number of other places were visited, but conditions seemed so nearly like those at Damru that samples were not collected, except at Kom-el-Akhdar. The analyses from this place are given on page 22, and a comparison with the Damru samples will show that the similarity deduced from field examinations actually exists.

RECLAMATION WORK AT KOM-EL-WAHAL.

Probably the most extensive attempt at salt land reclamation in Egypt is that by the Societé Anonyme du Behera. In 1894 this company purchased from the Daira Sania, at a cost of £E.240,000

($1,200,000), 123,000 acres of land, the most of it lying in the lower and northern part of the Delta, between the two branches of the Nile. At the time this land was bought practically all of it was out of cultivation, due to excess of water and salt. Since 1894 small tracts have been sold, and at this time the company holds about 115,000 acres.

The system of reclamation is very similar to the one in use at Abukir, and consists of canalization, leveling, flooding, and growing dineba or barnyard grass as the first crop. (See Pl. V.)

The land is first banked and flooded in large tracts, thus really returning to the basin method of irrigation employed in this district until the Arabian conquest desolated the country. As the washing proceeds the land is divided up into smaller tracts and finally drains, 31.4 inches deep, are dug every 50 meters (164 feet) in the worst land, or every 100 meters (328 feet) in land less saline. Washing is carried on as at Abukir until a stand of dineba can be secured, after which other crops are planted. Rice is used a great deal in rotation with dineba and clover. The dineba seed is sown at intervals until a stand is secured. Frequently the dineba is sown on land yet very saline and a scattering stand secured. Another sowing is then given, and so on until a good stand is secured. The land is then planted to other crops, either clover or rice, and finally to cotton. (See Pls. VI and VII.)

The inspection given this area was a hasty one, but it seemed to the writer that the reclamation was not as thorough as it should be before the land is sold.

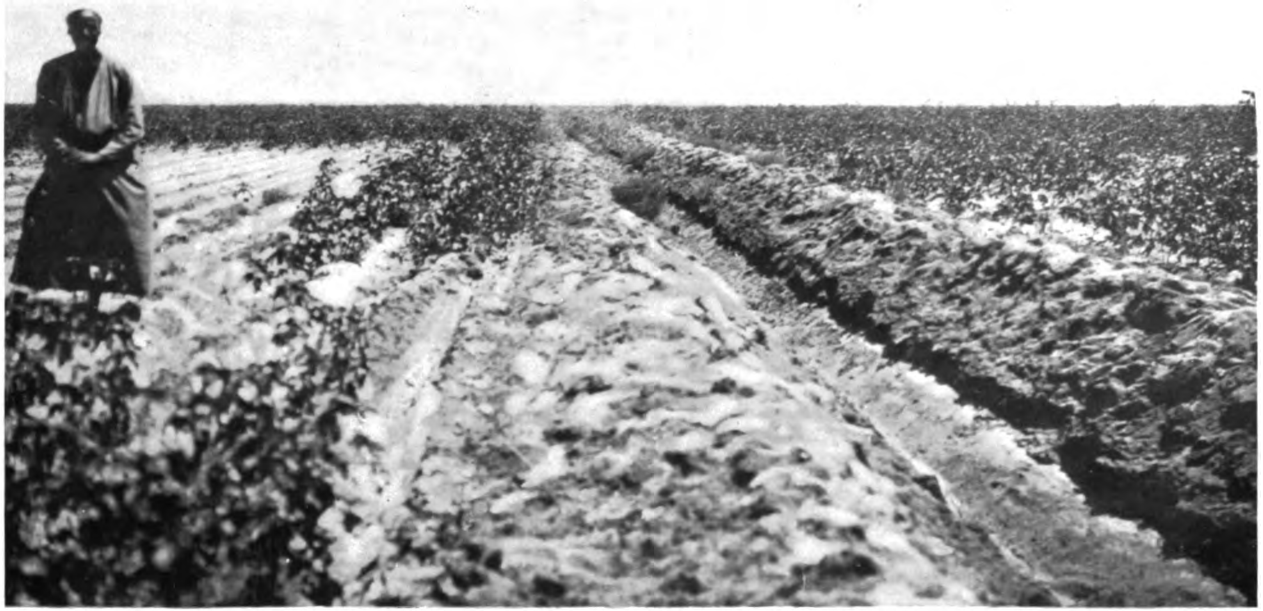
Land is washed until it will grow one good crop and is then sold. The new owner frequently considers the soil sufficiently free from salt to grow any crop, and too often attempts to grow cotton and corn and other crops which receive relatively small amounts of water and allow large quantities to evaporate from the surface of the soil. The result has been that considerable areas once considered reclaimed are now becoming salty again, and confidence in the methods of reclamation is being shaken. The criticism is not on the methods of reclamation in use, but applies to methods used by the new owner of the land.

The most successful way to handle this newly reclaimed land is, as has been shown, to continue the reclamation, at intervals of three or five years, by introducing into the rotation some crop which will withstand large quantities of water.

The Societé du Behera, under the management of Mr. Theobold Smith, has constructed and is operating a steam leveler which is of interest and should be of use in certain portions of America. The scraper consists of an I girder with framework of iron for attachment power. This girder is drawn across the field by an 8-horsepower engine of the type used for steam plowing. The girder scrapes up a great quantity of soil, which is dumped where required. The machine

A FIELD WITH A SATISFACTORY STAND OF BARNYARD GRASS.

Three years ago this soil carried 8 per cent of alkali and was totally unfit for agricultural crops. This test indicates that it is completely reclaimed for such crops as clover.



FIELD OF COTTON ON NEWLY RECLAIMED LAND.

After the soil is sufficiently reclaimed for clover, cotton is planted. This picture shows a spot where the alkali is too strong for cotton, and on which dineba or barnyard grass will again be planted and the land heavily flooded for more complete reclamation.

does not thoroughly level the land, but leaves it in slight ridges and heaps, necessitating a final leveling with horse or bullock scrapers.

RECLAMATION OF SALT LAND AT BUSILI.

Through the kindness of Mr. T. S. Richmond, engineer of the Abukir Company, Limited, a visit was paid to the village of Busili, near which reclamation work was being carried on both by the natives in their own way and by Europeans following the methods in use at Abukir.

The land at Busili lies directly west of the Rosetta branch of the Nile, between the river and the salt lake Edku. The land is only a few feet above sea level and has been flooded from time to time by the Nile. Much of it has been out of cultivation for such a long time that alkali salts have accumulated at the surface and the land is sterile.

The native method of farming this land can hardly be called reclamation, for that is never accomplished except under the most favorable circumstances. Their plan is to bank the land without any attempt at underdrainage, flood it, and sow rice. The rice is sown on the surface of the water. By this method the first year's crop is often a failure, but the flooding sweetens the immediate surface of the soil and allows the rice to grow the second year and thereafter. It is extremely doubtful, however, if more than the immediate surface is reclaimed, because there is such poor underdrainage. Whenever any other crop than rice is grown, a good portion of the land develops salt and the crop hardly pays. The land is very fertile, and with underdrainage its cultivation should prove most profitable.

An attempt was made to determine the amount of salt which rice will withstand, but this could not readily be done, as it is very difficult, without special sampling devices, to collect samples of the soil covered with water. These were not at hand, so samples were collected where the water had temporarily drained off. Samples of the standing water were also examined. The water contained about 150 parts of salt per 100,000, and the soil, to a depth of 12 inches, contained about 2.04 per cent of salt. Since the rice roots extend only a few inches into the soil, and since the water is kept fresh by constant flooding, the results of the examination of the soil do not necessarily indicate that rice is an alkali-resistant crop.

The first attempt at reclamation under thoroughly efficient methods is but now being made. An area of 500 acres is being prepared by Mr. Richmond upon plans very similar to those so successfully in operation at Abukir. Here the tertiary (gata) drains are 200 meters (656 feet) long, and 84 meters (275 feet) apart. The secondary drains run directly beside the secondary canals (see fig. 4) and act as seepage drains. This method saves somewhat in ditches, the greater distance between the tertiary drains being considered allowable because the land is not so impervious nor so saline as at Abukir. On much of the land Mr. Richmond hopes to obtain a stand of dineba during the coming winter.

There is a great deal of land of this character in Lower Egypt; that is, land which lies but a few feet above the level of the sea, yet is never covered with salt water. The reclamation of such land is being carried on in many places with success and at a profit. The problems found here are duplicated in many of our western plains and valleys, and it is certain that much similar land abandoned in America can be taken up and brought into profitable cultivation by the adoption of like methods.

The following table shows the results of the chemical analyses of samples collected near Busili. By comparison with the analyses given on pages 25, 33, and 37, the type of alkali found here is seen to be that common to the lowlands of the delta.

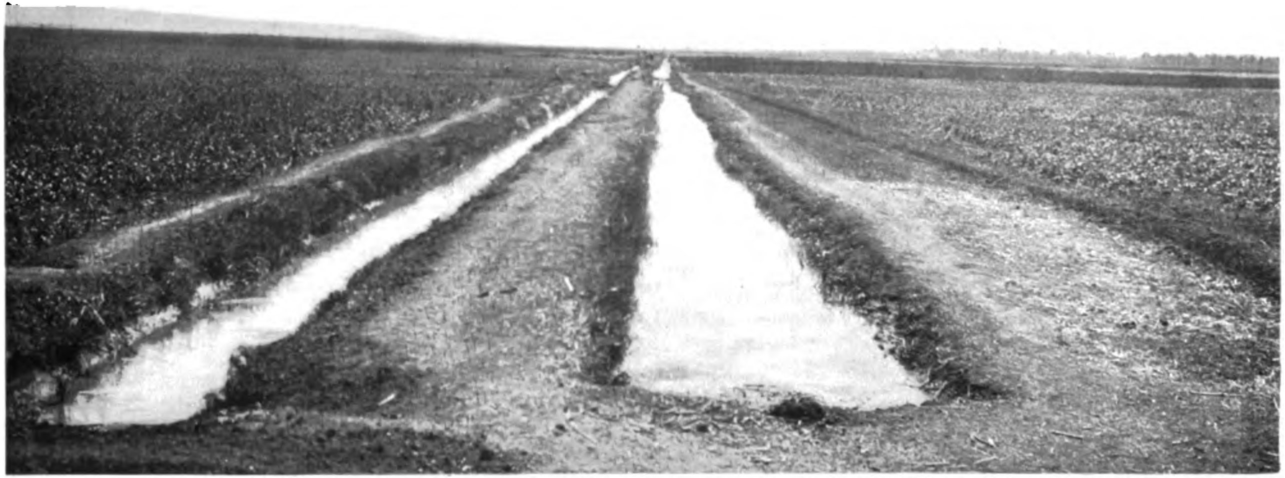
Analysis of soils from Busili.

Constituent.	7559, crust.	7547, 0 to 12 inches.	7548, 0 to 12 inches.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	2.69	3.33	1.94
Magnesium (Mg)	3.24	Tr.	Tr.
Sodium (Na)	30.16	26.25	30.60
Potassium (K)	1.20	10.68	5.56
Sulphuric acid (SO_4)	3.12	8.03	11.38
Chlorine (Cl)	59.23	48.19	42.98
Bicarbonic acid (HCO_3)	.36	3.52	7.54
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	4.40	11.36	6.53
Sodium sulphate (Na_2SO_4)	....	....	10.04
Calcium chloride ($CaCl_2$)	3.87	....	....
Magnesium chloride ($MgCl_2$)	12.71	....	....
Potassium chloride (KCl)	2.29	20.37	10.56
Sodium chloride (NaCl)	76.23	63.49	62.59
Sodium bicarbonate ($NaHCO_3$)	.50	4.79	10.29
Per cent soluble	16.39	2.04	1.42

Sample No. 7547 was collected near Messana village, about 2 miles south of Busili station, from a rice field where the land was saline and rice just growing. This probably represents the limit for growth of rice in this type of alkali. The land at this place was not covered with water, but had been dry for a few days. The farming was being done by the native method, no attention being paid to drainage. (See Pl. VIII.)

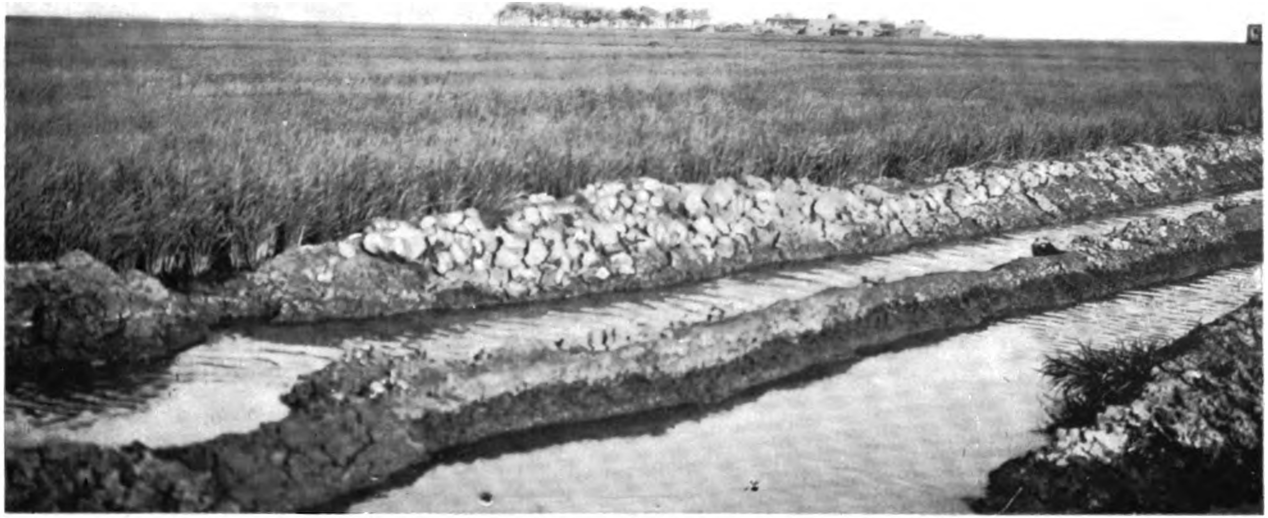
Sample No. 7548, collected near the same place, was from a cotton field, where the cotton was living. This represents the limit in quantity of alkali of this type in which Egyptian cotton will grow.

Sample No. 7559 is the alkali crust scraped from the surface of the soil.



COTTON FIELD FULLY RECLAIMED FROM ALKALI.

This shows the irrigation ditch on the right and the ever present drainage or infiltration ditch on the left, to quickly remove the seepage water.



A FIELD OF RICE UNDER NATIVE METHODS OF IRRIGATION WITHOUT DRAINAGE.

Rice, being a shallow-rooted crop and growing almost continuously in standing water, will thrive on a soil where crops requiring intermittent irrigation will not grow on account of the rise of alkali during the dry stage.

RECLAMATION WORK AT KOM-EL-AKHDAR.

Kom-el-Akhdar (Green Hill) is situated in the eastern edge of the depression in which lies Lake Mariut. The level of land around the hill is about sea level. Toward the west the land falls to the level of the present lake, which is maintained by the Egyptain government pumping station at Mex at 2½ meters (8.2 feet) below sea level. This area lies in the district famed in ancient days for its wines, and was then well cultivated and fertile. The land is now mostly charged with salt and alkali, and is practically worthless as far as profitable agriculture is concerned.

A few years ago a French company bought 10,000 acres of this land and attempted its reclamation. Of this tract 1,500 acres were already sufficiently free from salt to be brought into cultivation. These areas of good land are situated upon slight ridges which extend from the higher lands on the east out into the low delta lands on the west.

This company constructed a canal from the Nile, nearly 50 miles distant, established a large pumping station, dug canals and drains at right angles to each other, extending them all over the property, and built buildings, a church, and dwellings for the natives. Very solid brick and masonry irrigation works were installed. A pumping plant for the drains was put in and an outlet was dug. Steam machinery for farm use was bought, farm tramroads constructed, and in short the property was in every way prepared for extensive agricultural operations. Yet the land was never reclaimed from salt. It is said that £E.980,000 ($4,900,000) were spent upon the property. This is at the rate of nearly £E.100 ($500) per acre. The company reached the end of its resources, and the land has been for sale for a number of years. Recently it was sold for £E.67,000 ($335,000), or at the rate of about $33.50 per acre.

When visited in September, 1902, the property was said to contain about 1,500 acres of arable land. This was the land that was most easily reclaimed, or land which more likely never had been salty—probably the original 1,500 acres of good land. Remains of extensive ditches and canals, overgrown with weeds and filled with sediment, were seen on every hand. The stone and masonry irrigation works were falling to pieces, the church was half in ruins, and alkali weeds and salt plants were thriving on every hand.

As lessons are to be learned from every failure, as well as from every success, careful inquiry was made into the methods adopted by the company, to see if in them lay the cause of the waste of so much money. Certainly the land and the kind and amount of salt present were not to blame, for in other parts of Egypt such lands had been successfully washed and are now returning harvests of great value.

A sample of soil was collected from a spot representing an average of the land which had not been washed, and an analysis made in this Bureau. The following table gives the result of this analysis:

Chemical analysis of alkali soil from Kom-el-Akhdar.

Ions.	No. 7555, 0 to 12 inches.	Conventional combinations.	No. 7555, 0 to 12 inches.
	Per cent.		*Per cent.*
Calcium (Ca)	3.07	Calcium sulphate ($CaSO_4$)	10.43
Magnesium (Mg)	2.00	Magnesium sulphate ($MgSO_4$)	9.90
Sodium (Na)	28.83	Potassium chloride (KCl)	3.62
Potassium (K)	1.90	Sodium chloride (NaCl)	60.88
Sulphuric acid (SO_4)	24.56	Sodium bicarbonate ($NaHCO_3$)	1.41
Chlorine (Cl)	38.62	Sodium sulphate (Na_2SO_4)	13.76
Bicarbonic acid (HCO_3)	1.02	Per cent soluble	8.2

The salts in this soil are very similar to those found at Damru (see analysis on page 37), and are thought to be characteristic of the largest areas of alkali land of Lower Egypt. If reclamation is possible at Abukir, Damru, and Kom-el-Wahal, such lands as those at Kom-el-Akhdar should be easily brought into cultivation.

As near as could be gathered the failure was due to one or all of the following causes:

(1) The ditches were not close enough together to permit ready or rapid washing of the soil. The soil is heavy and very impervious, being the finest sediment from the Nile, the last to be dropped by the water, as is all of the soil of the delta at a distance from the main channels of the river. The subsoil retains its tenacity to great depths and is everywhere charged with salt. Ditches in such heavy and impervious soil should be close together, certainly not more than 50 meters (164 feet) apart, if their effect is to be immediately felt. The efficiency of ditches varies approximately inversely as their distance apart, so that ditches 150 meters apart would act twice as quickly and be twice as effective as ditches 300 meters apart.

(2) The ditches should have taken advantage of the slope of the land and should have followed the lowest levels. Instead of following this method the ditches were run on a rectangular system, and in many cases, owing to local irregularities in the soil and to the marked ridges which run through the land, were not deep enough to properly carry away the underground water. In ditching land advantage should be taken of the topography, and the main and primary drains should invariably follow the lowest portions of the land. Canals, on the other hand, should follow the high land, so that there may be no necessity to raise the water artificially in order to irrigate the adjacent soil. If land is thoroughly protected by drains there need be no fear that seepage water from these high-line canals will injure the land.

(3) Reclamation was attempted on too large an area at once. Will-

cocks estimates that it requires four times as much water to supply an acre with basin irrigation as with perennial irrigation. When land is being washed to free it from salt the amount of water needed is at least as much as for basin irrigation. Canals in the delta are dug to supply the land with perennial irrigation, and therefore have not the capacity to supply all the land with basin irrigation. For this reason it is never safe to take up a large area for reclamation at one time. It seems that in the Kom-el-Akhdar reclamation large areas were undertaken at one time, and that the work on each of these areas could not be carried on as thoroughly as would have been possible in smaller areas.

(4) The reclamation work was not carried on as thoroughly as it should have been before cotton farming was attempted. This is an important fact about salt-land reclamation; thoroughness is essential to success. The attempt to plant crops unsuited to the soil in land half reclaimed results in a rise of salt from the subsoil, and often in great detriment to the soil.

Failure in Egypt frequently results from the owner of land under reclamation renting land partly reclaimed to fellahs. The methods of farming used by the fellahs with perennial irrigation do not further the reclamation; in fact, as a rule the land goes backward. Land in which the surface foot of soil only is washed free from salt may have every appearance of being reclaimed, and for all practical purposes is as valuable as thoroughly reclaimed land, but great care must be exercised that the underlying salts do not rise into the upper foot, where the roots are active.

This property at Kom-el-Akhdar has recently been bought, and is to be farmed by a man of wealth. New methods of reclamation are to be used, and it is hoped that success will follow.

At this point it seems pertinent to emphasize the fact that success in alkali-reclamation work depends entirely upon the thoroughness with which the work is done, and upon the persistency with which the one idea of getting rid of the salt in the surface soil, and keeping that in the subsoil from rising, is adhered to. Reclamation attempted by a stock company is very apt to be hurried, in order that dividends may be paid promptly. Should reclamation work be undertaken in this country, this fact should be kept in mind, and during the first few years stockholders should not expect to receive profits.

ALKALI-LAND RECLAMATION IN UPPER EGYPT.

The land of Upper Egypt is, in the main, still irrigated by the old basin method. As rapidly as possible, however, these basins are being converted into land under perennial irrigation. The change was instituted by the Khedive Mahomet Ali many years ago. This Khedive owned large tracts of land in Upper Egypt, and in the readjustment of the finances of the country under the reign of Ismail these personal estates were turned over to the government in payment of debt. The Daira Sania administration has control of these lands at the present time.

During the last forty years much of this land has been allowed to lie idle. Under the basin method of irrigation, water stood on the land from six to eight weeks each year, thus thoroughly washing the soil and preventing the accumulation of a harmful quantity of soluble salts. When, however, it was allowed to lie idle, the slow upward capillary movement brought to the surface the salts which were formerly never present there in any great quantity, but which were scattered through a great depth of soil. The analysis of Sample No. 7551 shows the character of the surface foot of soil after being out of cultivation forty years. The analysis of Sample No. 7560 shows the character of the salts collected from the surface of the soil at another place.

Analyses of soils from near Magaga.

Constituent.	7560, crust.	7551, 0 to 12 inches.
Ions:	*Per cent.*	*Per cent.*
Calcium (Ca)	9.40	12.39
Magnesium (Mg)	8.31	3.65
Sodium (Na)	14.19	17.50
Potassium (K)	1.27	2.15
Sulphuric acid (SO_4)	10.28	11.07
Chlorine (Cl)	55.94	51.98
Bicarbonic acid (HCO_3)	.61	1.24
Conventional combinations:		
Calcium sulphate ($CaSO_4$)	14.56	15.69
Sodium sulphate (Na_2SO_4)		1.72
Calcium chloride ($CaCl_2$)	14.61	21.49
Magnesium chloride ($MgCl_2$)	32.59	14.31
Sodium chloride (NaCl)	35.44	43.21
Potassium chloride (KCl)	2.41	3.55
Sodium bicarbonate ($NaHCO_3$)	.54	1.72
Per cent soluble	17.61	7.71

One peculiarity brought out by these analyses is the presence of large quantities of calcium chloride. This salt, from its tendency to absorb moisture from the air, keeps the surface of the soil moist all of the time. A sample kept in a cloth sack in the hotel room at Cairo absorbed so much moisture as to drip and form a pool of water.

This type of alkali seems to be characteristic of much of the desert land lying on each side of the Nile in Upper Egypt. Mr. Willcocks, of the Daira Sania, called attention to the fact that all along the Nile Valley soluble salts were present in quantity in the rocks of the desert hills. These hills were examined in a number of places and everywhere salts were found to be present. One sample was collected from the surface of the desert about 4 miles east of Helwan. The analysis of this sample appears in the following table:

Analysis of alkali soil from desert east of Helwan.

Ions.	Sample 7562.	Conventional combinations.	Sample 7562.
	Per cent.		*Per cent.*
Calcium (Ca)	28.54	Calcium sulphate ($CaSO_4$)	43.75
Magnesium (Mg)	1.11	Calcium chloride ($CaCl_2$)	43.34
Sodium (Na)	1.49	Magnesium chloride ($MgCl_2$)	4.37
Potassium (K)	2.31	Sodium chloride (NaCl)	3.08
Sulphuric acid (SO_4)	30.89	Sodium bicarbonate ($NaHCO_3$)	1.09
Chlorine (Cl)	34.87		

Thus it would seem that the soluble salts which occur in the desert on each side of the Nile are mainly compounds of lime and magnesium. Out in the valley these salts are mixed with and modified by those salts carried in solution in the Nile water, resulting in the formation of alkali salts of the type already described.

Through the kindness of J. Birch Bey, inspector for the Daira Sania administration, a visit was made to the estates around Magaga and between that place and Fechn.

At the time reclamation was commenced there were 15,000 acres of land idle and charged with alkali. Birch Bey estimates that the cost of reclamation will be £E.30,000 ($150,000), and that the rental from this area when reclamation if completed will be £E.70,000 ($350,000) per annum.

The method of reclamation pursued is different from that in use in any other part of Egypt. The fundamental idea is a return to basin irrigation. Preliminary to washing the soil the land is leveled thoroughly. Steam plows are used to loosen the soil and bullock scrapers to move the loosened material, obliterating all unevenness, so that the soil may be easily and uniformly flooded. A great deal of the alkali is found on the immediate surface of the soil. Advantage is taken of this fact, and in the process of leveling the surface accumulation is scraped up and carried to the edge of the field to build dikes. Such a proceeding removes part of the salt, but this direct method could only be practicable in a country where labor is cheap.

The drainage ditches are about a mile apart and tail into one large ditch. These ditches are mainly of service as surface drains—that is, their use is practically limited to the removal of surface water. Their effect as underdrains is limited to the land immediately along the drains.

Upon the completion of leveling, ditching, and diking, the land is flooded to a depth of from 4 inches to 1 foot. This depth of water is maintained until the land is thoroughly sweetened, which requires from one to four years. The slowness of the work is due to the lack of adequate underdrainage. Were ditches more frequent it is thought that a more rapid sweetening of the soil would result.

One feature in the reclamation work being carried on by Birch Bey is worthy of imitation in all work of this character—that is, thoroughness. Land once thoroughly reclaimed gives no further trouble from alkali if farmed with intelligence, but land partially reclaimed reverts to its damaged condition in a few years. It has been found more economical to wash land four years and be sure of thorough reclamation than to attempt the cultivation of half-reclaimed soil, which invariably develops salt spots that spread from year to year.

Upon the completion of the reclamation, cotton, corn, clover, alfalfa, sugar cane, and all crops grown in the district can be grown without fear of a rise of alkali, but the partially reclaimed land is fit only for alkali resistant crops, or crops which will grow in standing water.

This method of alkali-land reclamation can only be used to advantage in areas where the depth to standing water is great; there must be sufficient depth of soil into which the excess of alkali can be washed. Where standing water is close to the surface, as in much of the alkali lands of lower Egypt, there is no place into which the salts can be washed, and underdrainage is necessary.

SUMMARY OF RECLAMATION METHODS.

There are three methods of alkali-land reclamation in use in Egypt. Each of these methods is successful under the conditions appropriate for its use, and all are worthy of being tried in America.

Colmatage or warping.—This method of reclamation consists simply in flooding land with muddy water long enough to allow the mud to settle, after which the clear water is drawn off and more muddy water run on. Very little attention is paid to drainage, except in so far as surface drains are dug to carry away the clear water. The popular impression prevails that by this method the alkali or salt is covered up with sufficient good soil to permit plant roots to thrive. As a matter of fact, the efficiency of the method depends much more on the fact that the alkali is washed down into and mixed with the subsoil, so that its concentration at the surface is diminished. The total amount of alkali in the soil is very slightly reduced, and when conditions again become favorable for the rise of the alkali it returns to the surface and proves as troublesome as before. Where, however, the depth of soil and subsoil above standing water is great, and where rice or other wet-land crops are to be grown, colmatage may advantageously be used for reclamation. Large quantities of water are required and much land is made swampy. As an efficient and permanent remedy for alkali land this method can not be recommended for general use.

Flooding with open drains.—This is the method in common use in Egypt. The land is thoroughly leveled, open ditches to a depth of 32 inches are dug at intervals of 150 to 450 feet, and the land is banked up and flooded to a depth of 4 inches until sufficiently leached of alkali or salt to permit plant growth. This method is thoroughly effective for the removal of salt, but it has the objectionable feature of open ditches.

Flooding with tile drains.—This method has only been tried experimentally in Egypt, but promises to be the most rapid and effective way of reclaiming the land. Tile drains are placed 30 inches deep and 35 feet apart, at a cost of $30 per acre.

Application to American conditions.—In applying these methods of reclamation to American conditions there are a number of factors which enter into the problem and make necessary certain changes. American farmers have a well-grounded dislike to open ditches in fields. They take up a large amount of valuable land, require an annual outlay in cleaning and deepening, necessitate the building and annual repair of bridges, and prevent or hamper the use of machinery in agricultural operations. Tile drains take up no room, render no land unavailable for cropping, require little or no repairs if properly laid at the start, and are efficient for many years. One hundred feet of open ditch 7 feet wide occupies 700 square feet of land; the value of this, at $100 per acre, would be $1.61. The cost of digging 100 feet of open ditch of this width, 3 feet deep, is at least $4. The cost, in our Eastern States, of digging, laying tile, filling the trenches, and purchase of 4-inch tile for 100 feet of drain is about $4, so that there is a difference of $1.61 per 100 feet in favor of the tile. If allowance is made for cost of bridges and annual cleaning of open ditches, the difference will be still greater.

The soils in arid America are generally light in character and do not stand well in bank, so that great trouble would be experienced in maintaining small open ditches.

For these reasons alkali land reclamation by means of open ditches is not to be recommended for general use. In the larger drains, where very large pipe would be required, open ditches may be used, but in a great many localities some kind of protection will be necessary to strengthen the banks and prevent their caving.

The irrigation season, except in certain parts of California and Arizona, is shorter than in Egypt, and in order to reclaim land within a reasonable length of time it will be necessary to place drains closer together. In this way the land will be reclaimed in a shorter time, because a greater quantity of water can be run through the soil in a given time. In an experiment on 40 acres now being carried on in a loam soil near Salt Lake City, Utah, the tile were placed 150 feet apart. This seems to be a good average distance at which to place tile. As the experiment progresses more definite information regarding the time required for reclamation can be given.

It is hardly practicable to recommend the use of such crops as dineba, samar, and rice in America for use during reclamation, but sorghum, certain of our native grasses, alfalfa, and possibly in California and Arizona, Egyptian clover may be substituted to suit the conditions. As the experimental work progresses other and more satisfactory crops may be found.

Pumping for the removal of drainage water is very expensive. It is so considered wherever used, though frequently conditions make it profitable. Pumping from large drainage systems has certain very definite limitations, and wherever possible a gravity outlet should be dug. Often a gravity outlet proves very expensive to install, but unless there are great difficulties in the way it will be found cheaper and more effective in the long run.

ACKNOWLEDGMENTS.

The writer is indebted to Mr. Thomas H. Kearney for assistance and advice during the journey through Egypt, and in preparing this report. In Egypt the investigations were made possible through the cordial help of the officials in charge of reclamation work. Especial thanks are due to Messrs. W. Willcocks, J. Birch Bey, A. Lucas, J. Langley, A. Souter, and T. S. Richmond.

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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 33.
MILTON WHITNEY, Chief.

CALCIUM SULPHATE IN AQUEOUS SOLUTIONS:

A CONTRIBUTION TO THE STUDY OF ALKALI DEPOSITS.

BY

FRANK K. CAMERON AND JAMES M. BELL.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1906.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., April 4, 1906.

Sir: I respectfully transmit herewith the manuscript of a technical paper entitled "Calcium Sulphate in Aqueous Solutions: a Contribution to the Study of Alkali Deposits," which I recommend to be published as Bulletin No. 33 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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CALCIUM SULPHATE IN AQUEOUS SOLUTIONS.

INTRODUCTION.

Calcium sulphate in its various modifications is of considerable importance in agricultural investigations. It is probably a common constituent of soils, although in the surface soils of humid regions it is seldom present in noticeable amounts. In arid regions, however, it is a common mineral component of the soil, sometimes forming a large percentage of the whole, even in soils of considerable agricultural importance. For instance, in the Pecos Valley, New Mexico, there occurs an important soil type, the Gypsum loam or "yeso," which is almost entirely gypsum, the dihydrate of calcium sulphate,[a] with possibly some anhydrite—the salt free from combined water.

Calcium sulphate exists in several forms. The most common is known as gypsum, which is the dihydrate ($CaSO_4.2H_2O$), and is found widely distributed in nature both in massive deposits and in well-defined crystals or crystal masses. A hemihydrate ($CaSO_4.\frac{1}{2}H_2O$) also exists and is the common form in which calcium sulphate separates from solutions in boiler and pan scales. It is a metastable form; that is, it is stable under a wide range of conditions, but only in the absence of a more stable form. Under ordinary conditions it would change more or less gradually to gypsum or anhydrite, if some of the latter were brought into contact with it. Natural anhydrite ($CaSO_4$) or calcium sulphate containing no water of crystallization, is found in nature generally in deep-seated regions where it has separated from saline solutions in past times and been subsequently protected from the continued action of moist air. It should be observed, however, that the anhydrite must have separated from solutions of rather high concentration with respect to the more soluble salts, for gypsum is the form which separates from such a solution when the concentration of the other salts is low. Where anhydrite has been found at or near the surface and in such position that it comes in contact with moisture, it is always associated with gypsum, into which it is slowly and gradually changing. Another form of anhydrite, the so-called artificial anhydrite, can be prepared in the laboratory under certain well-defined conditions, and differs from the natural anhydrite mainly in having a greater solubility and possessing only metastability. Several other forms of calcium sulphate have been described from time to time, but their existence has not been confirmed by subsequent investigation.

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[a] Report No. 64, Field Operations of the Division of Soils, U. S. Dept. Agr. (1899), p. 67.

These several forms of calcium sulphate are each stable under certain well-defined conditions, but, with disturbance or changes in the conditions, there may be a more or less ready transformation of one form into another. Thus under ordinary conditions of temperature, and in contact with the air, gypsum is the stable form. But both the hemihydrate and anhydrite can and often do exist under these conditions as metastable forms, because the transformation to the more stable gypsum is very slow. In contact with pure water, gypsum is the stable form up to a temperature of about 66° C., when natural anhydrite becomes the stable form, but the solubility of gypsum has frequently been determined at temperatures up to 100° C., because at these higher temperatures the transformation of the less stable gypsum to the more stable anhydrite is quite slow. The temperature at which gypsum ceases to be stable and anhydrite becomes the stable form is lowered by the presence of other salts, being about 33° in a saturated solution of sodium chloride and about 11° in a saturated solution of magnesium chloride. Nevertheless, the solubility of gypsum can be determined in this latter solution, since gypsum can be kept in contact with it for weeks at ordinary temperatures without appreciable change into the more stable form of anhydrite.

The slowness with which these transformations take place long proved a serious stumbling block in studies of calcium sulphate solutions and led to many misconceptions regarding its properties and conduct toward other substances. But recent investigations, notably the brilliant series carried out by van 't Hoff with Meyerhoffer and other coworkers, have yielded an extensive and precise knowledge of the transformations of the several forms of calcium sulphate and the conditions under which the several forms exist in stable equilibrium.

The solubility of calcium sulphate in pure water is considerable, a saturated solution at ordinary temperatures containing upward of 0.2 per cent of the salt. Moreover, with this substance, there is a marked tendency to the formation of supersaturated solutions, and solutions have been observed containing several times the amount of calcium sulphate that can be dissolved under equilibrium conditions. For this reason, the large number of determinations of the solubility of calcium sulphate which have been made in the past are very discordant, and this fact probably accounts also for some of the many other difficulties which have arisen in the study of this substance both in the laboratory and in the field. Recent careful work, however, by several investigators has established the real solubility of this substance with a very satisfactory degree of exactness. With rise of temperature the solubility of calcium sulphate gradually increases to a maximum which is reached at about 40° C., the solution then containing about 0.21 per cent. With further increase in temperature the solubility steadily decreases, and at 100° C. it is less soluble than in ice water. The solubility may be increased over three times by the addition of sodium chloride and over four times by magnesium chloride, a reaction taking place, to some extent at least, between the calcium sulphate and the other salt whereby calcium chloride is formed, and at the same time a sulphate of sodium or magnesium, as the case may be. Undoubtedly it is in this manner that the soluble sulphates are formed in many of the cases of "alkali" found in arid areas, where sodium chloride is the predominating salt in contact with soils containing much calcium sulphate. A similar reaction takes place between sodium chloride and calcium carbonate, and a chemical classification of alkali conditions can be made very conveniently on this basis, as was proposed in Bulletin No. 17 of this Bureau, and it is from this point of view that this bulletin has been prepared, our present knowledge of the action of water and other salts on calcium sulphate being brought into an orderly arrangement as a chapter in the larger study of the chemistry of "alkali." A somewhat similar investigation on the effect of water, salts, and carbon dioxide upon calcium carbonate is in progress, together with a study of absorption and leaching phenomena, which it is believed will give a clear and comprehensive view of the chemical and physical principles involved in the management of soils containing alkali, and which is already suggesting important modifications of the treatment of this difficult and vexatious problem in the agriculture of irrigated areas. Intimately connected with this problem is the use of irrigation waters carrying sulphates and calcium salts, as well as the use of waters carrying other salts upon lands containing gypsum, and the effects which may reasonably be anticipated.

It has popularly been supposed that the composition of a drainage water from an alkaline soil could be easily predicated from a knowledge of the respective solubilities of the salts composing the alkali, and even the recent literature contains discussions of this subject based on the erroneous notion that the several components of a mixture will necessarily be removed in the order of the individual solubilities. That such is not the case, but that the relation of the vapor pressures of the solution and of the solid components, the formation of new molecular species (such as so-called double salts), as well as some other possible factors in each individual case, must be considered, has been known, though generally ignored, by chemists and other soil investigators. That the composition of the resulting solution with respect to the dissolved constituents remains constant so long as no one of the solid components disappears is well illustrated in a simple case—

by a mixture of sodium nitrate and potassium nitrate. If such a mixture be treated by successive portions of water, assuming of course that the temperature be kept constant, the composition of the several resulting solutions will be exactly the same so long as both solid salts remain in the mixture. Precisely the same sort of thing will happen with any mixture of solids, no matter how complex, and an interesting example has been under observation by this Bureau for several years.

A tract of land near Salt Lake City, Utah, has been under process of reclamation, tile drains having been installed and the land leveled and frequently flooded. When reclamation was undertaken, the surface soil of this tract contained, on the average, upward of 2.7 per cent soluble salts, while it now contains less than 0.3 per cent soluble salts. At frequent intervals since the installation of the drains, samples of the water from the outlet weir of the drainage system have been forwarded to the laboratory for analysis. The composition of the principal dissolved mineral constituents, at several different dates, are given in the following table:

TABLE I.—*Composition of soluble salts contained in the drainage water of the Swan tract.*

Date.	Ca.	Mg.	Na.	K.	SO_4.	Cl.	HCO_3.	CO_3.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1902—September	0.38	0.50	33.74	2.04	18.62	37.76	6.49	0.48
October	.23	.78	34.73	1.49	19.14	39.52	5.06	.29
November	.19	.74	34.42	1.40	18.61	40.46	3.95	.23
1903—May	.38	.61	34.48	.84	29.90	38.19	4.30	.25
June	.45	.85	34.18	1.09	17.52	41.00	4.23	.42
July	.50	.80	34.06	1.25	18.24	40.24	4.67	.30
August	.35	.90	34.40	1.12	17.15	42.37	3.48	.16
September	.49	.72	34.54	1.24	17.31	42.02	3.36	.33
October	.47	1.02	33.43	1.52	16.08	43.28	3.33	.30
1904—January	.15	.75	33.93	1.26	20.08	36.64	6.94	.25
February	.34	.78	34.59	.70	18.95	40.15	4.49	....
March	.29	.77	34.57	1.28	16.31	42.28	3.81	.19
April	.29	.70	34.28	1.37	20.93	38.04	3.33	1.06
May	.71	.74	26.92	4.01	21.26	40.93	4.05	1.38
June	.37	.70	32.60	3.55	19.94	37.42	4.05	1.37
August	.37	.86	33.85	2.13	17.12	41.31	3.20	1.16
September	.42	.79	34.10	1.35	19.01	39.85	4.11	.37
October	1.04	.60	33.01	1.86	21.42	36.63	4.68	.76
December	1.25	.70	32.62	1.69	19.89	37.44	6.18	.22
1905—February	.32	.67	33.59	.99	22.30	33.32	8.45	.36
March	.31	.66	33.46	1.30	21.60	33.86	8.46	.35
April	.35	.65	34.20	1.01	20.03	36.99	6.22	.55
May	.45	.86	33.43	1.20	20.59	36.04	6.96	.47
June	.40	.94	34.05	1.32	20.89	35.85	5.71	.84
July	.32	.69	33.67	1.30	21.17	34.94	7.23	.68
August	.35	1.04	33.12	1.58	21.58	35.92	5.72	.99
September	.42	.82	33.39	1.26	21.18	34.85	7.41	.67
1906—January	.55	.84	33.12	1.11	21.10	34.35	8.57	.36

It will be observed that the variations of the several constituents, within an interval of nearly four years, are very small, such differences as do appear being readily attributable to the relatively small changes in the actual concentrations of the drainage water at different times, produced by the addition of large quantities of water in flooding, some of which reached the tiles before coming to equilibrium with the soil components. Other similar examples might be cited, although no other field data are known to us which are as complete as in this case.

The data just presented is believed to be of more than ordinary importance, because it so well illustrates the character of the results which may be anticipated in a large number of cases in actual field-work. How long the practically constant percentage composition of the dissolved salts would continue in the drainage water under continued flooding it is, of course, difficult, if not impossible, to predict. It is reasonably certain that sooner or later some one or more of the solid components in the soil would be completely removed, barring absorption or some other special phenomena, and the nature of the solution might then be very materially altered. As a practical matter, however, it should be remembered that the persistence of the several solid phases of the alkali mixture does not necessarily mean that they are evenly distributed in the soil, and that while they may be determining the composition of the solution as it passes into the drain tiles, some of these solid phases may have been removed from the surface soil, which would then hold a solution of different character, in which latter crops could very well grow. This seems to be true in the case just cited, as there is evidence that crops can now be grown on the tract if proper cultural methods be maintained to prevent the subsequent capillary rise of the water added in flooding. It appears certain, however, that in such cases the land can not be truly regarded as finally reclaimed until the change in the composition of the drainage water shows that there has been a complete removal of some of the solid salts from that portion of the soil which feeds the drains. The analysis of the drainage water is the most ready method of following the changes taking place within the soil. That the nature of the drainage water and the changes which it may undergo are problems of great practical importance is obvious when it is considered that agricultural plants display such marked difference in their tolerance of different salts and salt mixtures in their nutrient media. It is also important to note that a study of drainage water not only furnishes a clue to the nature of the soil solution in the land from which it flows, but that it may have an important bearing on the management of neighboring lands upon which it may be desirable to use the water again for irrigation or where the land may be affected through seepage.

In order to obtain a clear idea of the mechanism of the chemical phenomena presented by these drainage waters, it will be necessary to consider the mutual solubility effects of one salt upon another, the various salts or molecular species which may be formed, the vapor pressure of the resulting solutions and the solids in contact with them, and the converse problem to that which has been considered above—i. e., the separation from solution of the salts which the dissolved constituents may form. Since calcium sulphate or gypsum is a predominating component in a large number of cases of alkali and determines their characteristics, it is convenient to take up the investigation from the point of view of the solubility of this substance in aqueous solutions of other salts.

In considering the solubility of pairs of salts, there is one guiding principle commonly accepted—a result of the hypothesis of electrolytic dissociation—namely, that salts which yield a common ion mutually decrease each other's solubility, and that salts which do not yield a common ion increase each other's solubility. Exceptions are known, as for instance, the familiar one that sodium and potassium nitrate increase each other's solubility, while it is inconceivable that they could dissociate without the formation of a common ion.

Another interesting case is presented by magnesium sulphate and potassium sulphate, which mutually increase each other's solubility. Therefore, the indications of the dissociation hypothesis, however useful for purposes of classification, can not be accepted with confidence as general.

At a temperature of 25° C. the solubility of calcium sulphate in solutions of sulphuric acid presents a case similar to those just cited, in that increasing the quantities of sulphuric acid increases the solubility of the calcium sulphate up to a maximum point, after which further increase of the acid causes a decrease of the salt going into solution. It might be predicated here that in the more dilute solutions the dissociation of the sulphuric acid was of such a character as to yield HSO_4 ions rather than SO_4 ions, which alone it is possible to conceive the calcium salt as yielding. The evidence from studies of the transport number of sulphuric acid, as well as other considerations, rather decidedly negatives this supposition, however. With increasing concentration with respect to sodium, potassium, or ammonium sulphate the solubility of calcium sulphate does decrease, however, until a minimum point is reached, after which it steadily increases until some other solid than gypsum is also in contact with the solution. On the other hand, increasing concentration with respect to calcium nitrate or chloride steadily decreases the solubility of calcium sulphate as the fundamental hypothesis would require.

Increasing concentration with respect to the chlorides or nitrates of other bases than calcium causes an increase of the solubility of calcium sulphate, although in many cases a maximum solubility followed by a decrease is reached at some rather high concentrations, at which the indications of the dissociation hypothesis are not expected to hold. These higher concentrations are just those, however, which may reasonably be expected to occur in the crystallization of alkali salts and frequently, no doubt, in the leaching of them from the soil.

It is to be observed from the preceding paragraphs that no generalization exists from which the solubility of calcium sulphate in the presence of other salts could be satisfactorily anticipated, and the actual determination of the solubility curves for calcium sulphate in solutions of other salts was necessary to a correct understanding of the case. A comparison of the curves that have so far been investigated shows that in general the basic constituents rather than the acid constituents have determined the solubility of the calcium sulphate and the character of the curves. If the curves be compared for the chlorides and the nitrates at 25° C., it will be found that the bases in the order of their reacting weights, excepting calcium, have had in both series an increasing effect on the solubility of the calcium sulphate.

As has been pointed out above, the presence of another salt in solution may have a marked influence on the form of the calcium sulphate. For instance, if calcium sulphate be precipitated from a solution saturated with respect to magnesium chloride at ordinary temperatures, it will separate as anhydrite, which is the most stable form under these conditions. But gypsum, the dihydrate, can exist in contact with a saturated solution of magnesium chloride, and its solubility has actually been determined in such a solution, probably because the rate of transformation to the more stable anhydrite is very slow. But if gypsum be brought into contact with a solution of potassium sulphate at 25° C. and maintained at a concentration higher than 32.5 grams per liter, the gypsum can not remain as such, but quite rapidly disappears, and a new solid, syngenite ($CaSO_4.K_2SO_4.H_2O$), separates from the solution. If, instead of potassium sulphate, the solution contain about 160 grams potassium chloride per liter, and be also saturated with respect to sodium chloride, gypsum can not remain in contact with it, but syngenite will again be formed. Similar cases involving other so-called "double sulphates" of calcium might be cited, and are described elsewhere in this bulletin. Just what double sulphates of calcium or what hydrates of calcium sulphate can exist could only be determined by empirical experimentation. But there is a rule which furnishes a guide as to that form which will persist in equilibrium with any given solution—namely, that form which has the vapor pressure nearest to, but not higher than, the vapor pressure of the solution. Should, however, two solids when mixed together have the same vapor pressure as a solution containing the same constituents as the solids, which, obviously, for any given temperature, could occur only at one definite concentration of the solution, then both solids and the solution can remain in contact in stable equilibrium. For instance, at 25° C. gypsum and syngenite can remain in stable equilibrium with a solution containing 32.5 grams potassium sulphate and 1.58 grams calcium sulphate per liter. But if the vapor pressure of the solution be slightly lowered, as by adding more potassium sulphate, then gypsum will disappear, leaving syngenite alone in contact with the solution. On the other hand, if the vapor pressure of the solution be increased, as by abstracting some of the dissolved potassium sulphate (or what amounts to the same thing, diluting the solution), then syngenite will disappear and gypsum alone will be left in contact with the solution. This rule regarding the vapor pressures of solutions and the solids in contact with them is a special case of the more general principle of Le Chatelier, which may be stated thus: That any change from the outside of the system, disturbing any of the equilibrium factors, produces a corresponding reverse change within the system. There is always a tendency for the system to return to a condition of equilibrium accompanied by that particular change within itself which offers the least resistance to the external change imposed upon it. Increase of concentration induces the formation of that component or phase which tends to lower the concentration of the thing added; increase of temperature to the formation of that component or phase which absorbs the most heat; increase of pressure to the formation of that component or phase requiring the least volume; increase of vapor pressure to the formation of that component or phase which will most reduce the vapor pressure, etc. This general principle of Le Chatelier is of the utmost importance in considering complex systems, such as are presented by solutions in contact with salt mixtures, since through it the direction which changes in the system will take can not only be followed with certainty, but can, in the majority of cases, be readily predicted.

In considering such systems another useful generalization obtains which definitely describes the conditions of equilibrium. This is the phase rule. A *phase* is defined as any portion of a material system which is homogeneous, and a *component* is any constituent (or group of constituents) comprising the system, which may vary in concentration independently of every other component. Thus ice floating in water would be a system comprising one component, water, in three phases—liquid water, solid ice, and vapor. Gypsum in contact with water would be two components, water and calcium sulphate, in three phases—solid gypsum, liquid solution of calcium sulphate in water, and vapor.

In accordance with the *phase rule* a system containing n components, comprising $n + 2$ phases, can exist at but one temperature and one pressure, the composition of the phases being also definitely determined. If the system comprises $n + 1$ phases, it can exist over a range of pressure, or temperature, or concentration of some one or other of the phases. But arbitrarily fixing some one or other of these variables, for instance the temperature, the system again becomes completely and definitely determined. Likewise if the system comprises but n phases, it will be necessary arbitrarily to fix two of the possible variables in order to determine it definitely. For instance, if the system, gypsum in contact with a solution of potassium sulphate, be considered, there will be three components, namely, calcium sulphate, potassium sulphate, and water. At lower concentrations of the solution there will be three phases, solid gypsum, liquid solution of potassium and calcium sulphates, and the vapor above the solution. There are, then, three components, in three phases. If we arbitrarily fix one condition, as, for instance, keeping the system at 25° C., it can still exist over quite a range of concentration of the liquid phase or range of vapor pressure of the system or range of osmotic pressure of the solution, and it would be necessary arbitrarily to fix one of these variable quantities also before the system becomes definitely fixed under equilibrium conditions. If the concentration of the liquid phase be gradually increased with respect to potassium sulphate a new solid phase, syngenite ($K_2SO_4.CaSO_4.H_2O$) will appear, and the system will then have three components in four phases, and it will be sufficient definitely to determine it under equilibrium conditions by arbitrarily fixing any one variable. Thus, if we again arbitrarily keep the system at 25° C. the concentration of the liquid phase will be 32.5 grams potassium sulphate and 1.58 grams calcium sulphate, respectively, per liter, and the system can only exist at 25° when the concentration of the solution is as just stated. For if the concentration be increased, as by adding a little more potassium sulphate (the vapor pressure of the solution being lowered thereby), gypsum (which has the higher vapor pressure) will disappear and syngenite alone will be the solid phase in contact with the solution. If, on the other hand, the concentration of the solution be lowered, as by adding a little more water, syngenite will disappear and gypsum alone will be the solid phase which persists. In either case the system is reduced to one of three components in three phases, and either solid by itself can remain in equilibrium with the solution over a considerable range of concentration of the solution.

Guided by these principles—the rule of Le Chatelier and the phase rule—it is possible to trace out the changes involved in the separation of several possible combinations of salts from even a very complex solution. This has been done with unusual completeness for those salts which comprise what is known as "white alkali." Conversely, from this knowledge, together with the necessary data as to mutual solubility effects, it is possible to make precise statements as to the leaching effects of water on alkali soils, which are in many respects totally at variance with the notions which have hitherto prevailed. It must not be overlooked that absorption, selective absorption, flocculation, deflocculation, and surface effects enter into this last problem, and these may considerably modify the expected results in any particular case, but, barring such effects, the guiding principle in leaching experiments is that the composition of the drainage waters will change only when some one or more of the solid phases disappears.

While calcium sulphate as such is sometimes found in the soils of humid areas in noticeable amounts, no especial significance seems to have been ascribed to it. As a mineral fertilizer it has generally been held to have a great value, and in its various forms, under the generic name of "land plaster," it is much used. Not only is it applied directly to the soil, but it is frequently applied with stable manures and composts to which it has been previously added, and it forms a very large part of the so-called "superphosphates" which have come into widespread use in recent years. It is, therefore, of obvious importance to have a knowledge of its solubility in pure water and in salt solutions in order to get an insight into how its use as a fertilizer may affect the character of the soil moisture, the great natural cultural medium from which plants draw their mineral nutrients.

In studying these problems much information of importance for other economic problems has been obtained. The setting of plaster of paris, much used in the arts, decorative work, and surgery, and the use of calcium sulphate in cements and in paper sizings, are dependent upon its relation to water and salt solutions. The use of water containing sulphates and calcium salts in boilers, with the formation of calcium sulphate boiler scale (probably the hemihydrate), and the formation of calcium sulphate pan coatings in the evaporation of the brines in salt works, are practical problems which have thus far largely defied a satisfactory treatment and can be intelligently attacked only on the basis of the facts brought out in the following pages.

The purpose of this bulletin is to bring together and arrange in a logical sequence the results of the numerous investigations which have been made on the relation of calcium sulphate to aqueous solutions. Experimental methods and details are either omitted or, if of unusual interest, are described but briefly, since the numerous references to the literature which are given will make them available to anyone who may be interested. In like manner practical applications of the results are merely indicated, as their discussion can be more profitably given elsewhere than in this necessarily technical description of a chemical problem.

TRANSFORMATIONS OF THE DIFFERENT MODIFICATIONS OF CALCIUM SULPHATE.

For a proper understanding of the solubility of calcium sulphate in water and in various aqueous solutions, it is necessary first to investigate the transformations which may take place in the degree of hydration of the solid and the crystalline forms in which the solid salt may appear. There are at least four well-defined forms,[a] (1) gypsum, $CaSO_4.2H_2O$, (2) the hemihydrate, $CaSO_4.\frac{1}{2}H_2O$, (3) natural anhydrite, $CaSO_4$, and (4) soluble anhydrite, $CaSO_4$. The last two modifications have very different solubilities in water, the latter being more soluble than the natural anhydrite. Two other modifications of calcium sulphate are claimed to exist by Rohland,[a] namely, calcium sulphate obtained by heating the hemihydrate just above 130° C., and calcium sulphate obtained at a red heat. Both these modifications may be hydrated, i. e., will take up water to form gypsum, under proper conditions, e. g., by contact with a solution of one of the alkali sulphates,[b] but they have no hydraulic properties and are therefore useless in the technical process of cementing. If, however, the heating takes place just above 525° C., there is a transformation into a modification quite similar to, if not the same as, soluble anhydrite, for it hardens very rapidly when it is moistened with water. Landrin[c] has shown that the velocity of hydration of burnt gypsum depends on the time and on the temperature of burning, but he obtained results rather different from those of Rohland upon the hydraulic properties of gypsum which had been burnt at high temperatures.

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[a] Van 't Hoff and Wilson, Sitzungsber, Akad. Wiss. Berlin, 1899, 599.

The anhydrides formed by burning gypsum have been divided into two groups by Potilitzin,[d] α-$CaSO_4$, burned between 120° and 200°, which takes up water readily and hardens, first forming the hemihydrate and then the dihydrate. The second modification, β-$CaSO_4$, is formed above 200° and does not harden, as water is taken up very slowly. The hemihydrate heated to 160° forms the α-modification, and at 350° the β-modification, while the hemihydrate is formed from gypsum at about 98°. Burnt gypsum must contain both modifications for good hydraulic properties, the hydrated compound formed from the α-modification filling in the spaces between the grains of the β-modification, which absorbs water but slowly.

The literature upon this subject, up to a few years ago, was quite bewildering and often contradictory, and consequently will be noticed rather briefly. The use of natural waters in steam boilers causes in many cases the formation of boiler scale, probably hemihydrate, which is a very poor conductor of heat and greatly reduces the efficiency of the engine. Johnston[e] noticed that in a boiler working under a pressure of two atmospheres the scale analyzed according to the formula $CaSO_4.\frac{1}{2}H_2O$. Rose[f] ascribed the formula $CaSO_4.H_2O$ to the substance which separated out from a sodium chloride solution carrying calcium sulphate. This solid lost one-third of its water when dried at 100° C., and in all probability was the hemihydrate. Million[g] states that artificially prepared gypsum loses three-fourths of the water of crystallization at 80° to 85°, while the natural gypsum undergoes the same change at 105° to 110°. The last half molecule of water is driven off above 200°. Plessy,[a] however, finds that both natural and artificial gypsum undergo the first change at about 110°. Million's contention is rather confirmed by experiments of later date by Zeidler.[b] According to Lacroix,[c] the first change takes place at 80° to hemihydrate and at 125° to anhydrite, and according to Guether[d] gypsum is completely dehydrated at 110°. The changes which gypsum undergoes at higher temperatures in sealed tubes have been investigated by Hoppe-Seyler,[e] who found that gypsum changes to the hemihydrate at 140° C., and in the presence of a saturated solution of sodium chloride the change takes place at the lower temperature of 125°. Solutions of calcium chloride also reduce the temperature at which the transformation takes place. Under all circumstances the hemihydrate spontaneously changed rather readily into one of the anhydrous forms.

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[a] Zeit. anorg. Chem., **35**, 201 (1903).

[b] Rohland, Zeit. anorg. Chem., **31**, 442 (1902).

[c] Ann. Chim. Phys. (5), **3**, 433 (1874).

[d] Jour. Russ. Phys. Chem. Soc., **25**, I, 207 (1893); **26**, 170, 221 (1894); **27**, 265 (1895).

[e] Phil. Mag. (2), **13**, 325 (1838).

[f] Ann. Phys., **93**, 606 (1855).

[g] Ann. Chim. Phys. (3), **19**, 222 (1847); Compt. rend., **24**, 695 (1847).

The formation of anhydrite has been investigated in the presence of salts which do not give up their water of crystallization readily. Pošepný[f] has found that anhydrite is formed from gypsum in the presence of such salts as calcium chloride and magnesium chloride. The results of Hoppe-Seyler have been confirmed by Rose,[g] who showed that gypsum lost water at even as low a temperature as 100°. At lower temperatures, however, gypsum always separated out from sodium chloride solutions, a result which has been confirmed by Hoppe-Seyler[h] in a later publication. These statements are contested by Roth,[i] who found anhydrite deposited from sodium chloride solutions at ordinary temperatures. The results of Spezia[j] indicate that anhydrite separates from a saturated sodium chloride solution at a pressure of 500 atmospheres, in spite of the fact that gypsum occupies one-eleventh less volume than the anhydrite and water resulting from the decomposition.

Vater[k] has evaporated at ordinary temperature these solutions, all of which contained calcium sulphate, viz, saturated sodium chloride, a solution containing sodium chloride and magnesium chloride in the same proportion as they are present in sea water, and a saturated magnesium chloride solution. In all cases he found that the new crystals were gypsum, while natural anhydrite, when placed in these solutions, remained unchanged. From these results it is impossible to come to any definite conclusion regarding the stable solid phase, and as the results of van 't Hoff and his coworkers have shown conclusively that the rate at which stable equilibrium is reached is exceedingly slow, it is improbable that Vater realized equilibrium conditions.

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[a] Compt. rend., **24**, 658, 812 (1847).

[b] Dingl. Poly. Jour., **180**, 471 (1866).

[c] Compt. rend., **126**, 360, 553 (1898).

[d] Ann. Chem., **218**, 297 (1883).

[e] Ann. Phys., **127**, 161 (1865).

[f] Verh. d. k. k. geol. Reichanst., 1869, 140.

[g] Ann. Phys., **145**, 177 (1872).

[h] Zeit. deutsch. geol. Gesell., **27**, 495 (1875).

[i] Sitzungsber. Akad. Wiss. Berlin, 1879, 89.

[j] Zeit. Kryst., **13**, 302 (1888).

[k] Sitzungsber. Akad. Wiss. Berlin, 1900, 269.

The investigations of van 't Hoff[a] and his coworkers have been conducted by somewhat different methods from those which have been cited in the foregoing paragraphs. The temperatures of transformation of one form into another have been obtained by dilatometric and tensimetric measurements. The criterion of the stability of any hydrate in the presence of a solution is that its solubility in the solution shall be less than the solubility of the other hydrates or of the anhydrous forms of the salt. This criterion may also be expressed in terms of vapor pressures, thus: The vapor pressure of the stable form in contact with any other modification of the salt must be lower than the vapor pressure of the solution in equilibrium with it. As soon as a temperature is reached at which the vapor pressure of the hydrate becomes greater than that of the solution in equilibrium with it, there is a change from that solid phase to the one which possesses the next lower vapor pressure. Using this principle as a guide, van 't Hoff and Armstrong[b] have determined at different temperatures the vapor pressure at which both the dihydrate and the hemihydrate[c] can exist in equilibrium, or, in other words, the vapor pressure of a mixture of these two salts at the temperature of the experiment. If to this mixture there is added a solution having a greater vapor pressure all the hemihydrate will change into the dihydrate, but if a solution of a less vapor pressure, the hemihydrate will become the more stable form. Thus, to find the inversion temperature and pressure of any solution it is sufficient to plot on a diagram the vapor-pressure curve representing the transformation of gypsum to the hemihydrate and the vapor-pressure curve of the solution. The point of intersection at which the vapor pressure of the solution becomes less than the vapor pressure of gypsum in the presence of the hemihydrate is the inversion temperature. From data given by Lescoeur,[d] Donnan,[e] and from their own measurements, van 't Hoff and Armstrong[f] have computed the vapor pressures of gypsum in the presence of the hemihydrate at temperatures from 0° to 110° C. in 5° intervals.

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[a] Zeit. phys. Chem., 45, 257 (1903).

[b] Sitzungsber. Akad. Wiss. Berlin, 1900, 559.

[c] The hemihydrate for these experiments was prepared by van 't Hoff and Armstrong by mixing 50 c. c. of nitric acid (sp. gr.=1.4) with 20 grams gypsum and keeping the mixture at 40° for eighteen hours. At the end of this time the resulting solid phase was washed with alcohol and dried quickly. The solid, upon analysis, showed 6.23 per cent H_2O, which agrees with the formula $CaSO_4.\frac{1}{2}H_2O$.

[d] Recherches sur la dissociation des hydrates salines, 1888, 115.

[e] Ann. Chim. Phys. (6), 21, 511 (1890).

[f] Loc. cit.; also van 't Hoff, Zeit. Elektrochemie, 8, 575 (1902).

These results are given in Table II, in which are given the vapor pressures of water, of a saturated solution of magnesium chloride, and of a saturated solution of sodium chloride. The actual composition of these solutions will not be constant, of course, as the solubility of the salts varies with the temperature. The table also gives the vapor pressure of gypsum in contact with one of the other modifications of calcium sulphate, since the vapor pressure of gypsum depends on the modification with which it is in contact. The symbol t_u signifies the temperature above which gypsum can not exist in equlibrium with the other modification of calcium sulphate; for, above this temperature the vapor pressure of gypsum in contact with the second modification would be greater than the solution saturated with this modification. This state of affairs is quite analogous to the case of Glauber's salt changing at 32.8° C. to anhydrous sodium sulphate. Above this temperature the vapor pressure of Glauber's salt in contact with anhydrous sodium sulphate is greater than that of the solution saturated with anhydrous sodium sulphate, and therefore Glauber's salt changes into the solid anhydrous sulphate and its saturated solution.

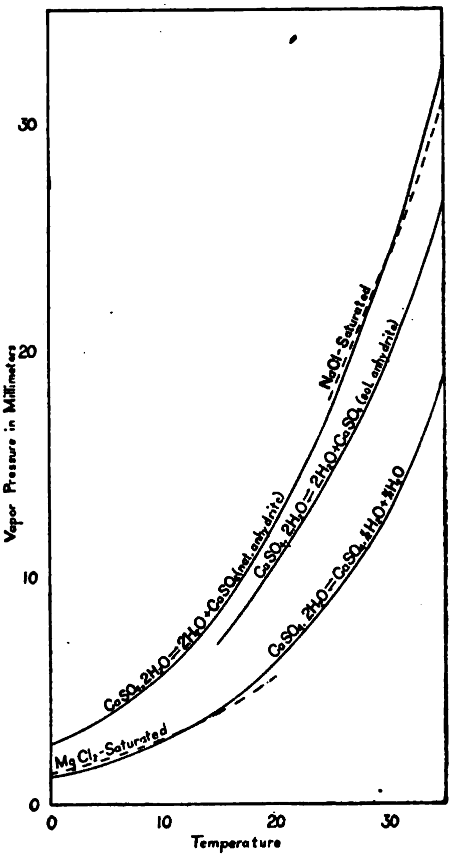

FIG. 1.—Vapor pressure curves (0° to 35° C.).

TABLE II.—*Vapor pressure of gypsum in contact with different solids and solutions.*

Temperature.	Water.	Saturated solution—		Gypsum in equilibrium with—		
		$MgCl_2.6H_2O$.	NaCl.	Hemihydrate.	Soluble anhydrite.	Natural anhydrite.
°*C.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
0	4.57	1.34	....	1.17	....	2.62
5	6.51	1.96	....	1.84	....	3.93
10	9.14	2.82	....	2.78	....	5.79
15	12.7	4.0	....	4.21	7.0	8.43
20	17.4	5.6	....	6.24	10.7	12.2
25	23.5	7.76	17.7	9.1	14.5	17.2
30	31.5	....	24	12.7	19.4	24
35	41.8	....	31	18.7	26.5	32.2
40	54.9	....	40.8	26.3	34	45.4
45	71.4	....	53	36.4	47.2	61.4
50	92	....	68.3	50	61.5	87.2
55	118	....	87.3	68	84	109
60	149	....	111	91.4	108	143
65	187	....	139	122	140	t_u=66°
70	233	....	173	161	185	....
75	289	....	214	210	242	....
80	355	....	263	272	314	....
85	433	....	....	350	407	....
90	526	....	....	446	t_u=89°	....
95	634	....	....	565	....	....
100	760	....	....	711	....	....
105	906	....	....	888	....	....
110	1,075	....	....	t_u=107°	....	....

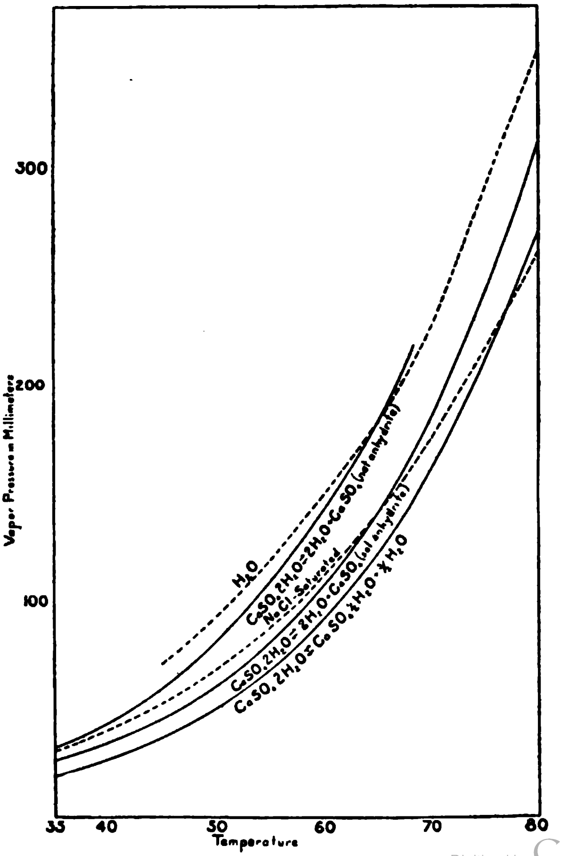

FIG. 2.—Vapor pressure curves (35° to 80° C.).

The vapor pressure for water is shown in figures 1, 2, and 3, and making the assumption that the small amount of calcium sulphate present in the solution does not materially alter the vapor pressure of water, the intersection of the two curves gives the inversion temperature. This temperature was found to be 107° C. and the pressure 970 mm. This result was confirmed by a study of the changes in volume of a mixture of the dihydrate and the hemihydrate in a dilatometer. At 107.75° the level of the mercury rose 6 mm. per hour, and at 106.75° the level of the mercury fell 2 mm. per hour. This indicates that the inversion temperature is very close to 107°. Portions of vapor pressure curves of some solutions have been given by van 't Hoff and Armstrong, and from these it is possible to determine the inversion temperature in the presence of salt solutions of these concentrations.

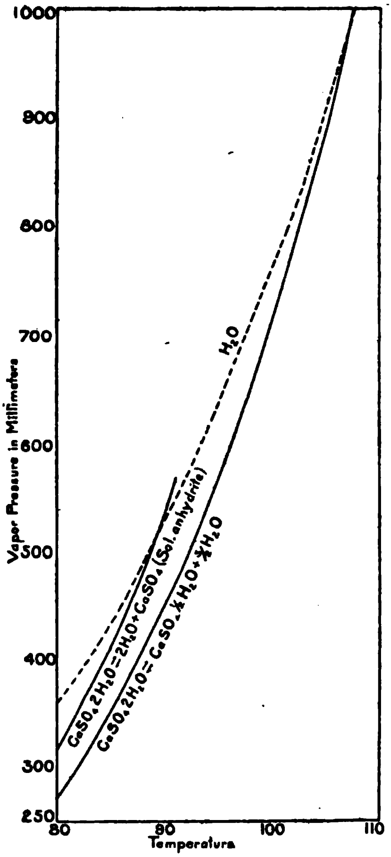

FIG. 3.—Vapor pressure curves (80° to 110° C.).

Table III indicates that the inversion temperature of gypsum to hemihydrate in the presence of a saturated solution of sodium chloride is about 76°, in good accord with the experimental result of van 't Hoff and Wilson at 77.1°. For some other sodium chloride solutions the data are given in Table III. It indicates that the inversion temperature in the presence of a 20 per cent sodium chloride solution is about 93°, a result in good accord with the solubility results obtained by Tilden and Shenstone, which will be discussed later. It indicates also that in the presence of a 3½ per cent solution of sodium chloride, which is about the composition of sea water, the inversion temperature is about 105°.

Table III.—*Vapor pressure of solid gypsum and of solutions in contact with it.*

Temperature.	Saturated solution of sodium chloride.		Temperature.	20 per cent solution of sodium chloride.		Temperature.	3½ per cent solution of sodium chloride.	
	Gypsum.	Solution.[a]		Gypsum.	Solution.		Gypsum.	Solution.[b]
° C.	*mm.*	*mm.*	*° C.*	*mm.*	*mm.*	*° C.*	*mm.*	*mm.*
75	210.2	214.0	90	446.3	462.0	100	710.8	744.0
80	272.4	263.8	95	564.8	556.7	105	887.8	887.4

[a] Nicol, Phil. Mag. (5), 22, 502 (1886).
[b] Wüllner, Ann. Phys., **103**, 529 (1858); Tammann, Mém. de l'acad. de St. Petersburg, (7), **35**, No. 9.

Table IV.—*Vapor pressure of solid gypsum and of solutions in contact with it.*

Temperature.	Saturated solution of calcium chloride.		Temperature.	15 per cent solution of calcium chloride.		Temperature.	Saturated solution of magnesium chloride.	
	Gypsum.	Solution.		Gypsum.	Solution.[a]		Gypsum.	Solution.
° C.	*mm.*	*mm.*	*° C.*	*mm.*	*mm.*	*° C.*	*mm.*	*mm.*
15	4.21	4.536	100	710.80	712.00	10	2.78	2.82
20	6.24	5.616	105	887.80	851.00	15	4.21	4.00

[a] Wüllner, Ann. Phys., **103**, 529 (1858).

Table IV indicates that for a saturated solution of calcium chloride the inversion temperature is about 17° and for a 15 per cent solution of calcium chloride about 100°, in accord with the solubility determinations of Tilden and Shenstone, which is discussed on page 48. In the presence of a saturated magnesium chloride solution this inversion takes place as low as 11° C.

The conditions under which gypsum can exist in the presence of the soluble anhydrite have been studied by van 't Hoff, Hinrichsen and Weigert.[a] According to Le Chatelier[b] this transformation takes place at 163°. Evidence of this change could not be observed by the former experimenters, although they do not deny the possibility of a phenomenon such as Le Chatelier describes. They have found that the change from gypsum to soluble anhydrite does not occur above 107°, as would be expected, but was found to take place below that temperature. Gypsum was placed in a dilatometer with a saturated sodium chloride solution and was heated to 76°. At that temperature an expansion in volume occurred, due to the reaction

$$CaSO_4.2H_2O=CaSO_4.\tfrac{1}{2}H_2O+1\tfrac{1}{2}H_2O.$$

When the dilatometer was cooled down again, the reverse process of contraction did not take place, and on cooling to 50° a considerable further expansion in volume took place, due to the reaction

$$CaSO_4.\tfrac{1}{2}H_2O=CaSO_4+\tfrac{1}{2}H_2O.$$

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[a] Sitzungsber. Akad. Wiss. Berlin, 1901, 570.
[b] Recherches expérimentales sur la constitution des mortiers hydrauliques, 1887–88.

That is, anhydrite is stable at a lower temperature than the hemihydrate in the presence of a saturated sodium-chloride solution. The temperature at which gypsum and this anhydrite (soluble) can exist in equilibrium has been found by van 't Hoff, Hinrichsen, and Weigert, by the same method as was adopted in studying the equilibrium between gypsum and the hemihydrate. This temperature is very close to 89° C., and therefore above that temperature gypsum changes into soluble anhydrite. As the formation of anhydrite from gypsum takes place at a lower temperature than the formation of the hemihydrate from gypsum, it follows that the hemihydrate must be metastable at all temperatures, and must change according to the equation

$$4CaSO_4.\frac{1}{2}H_2O = CaSO_4.2H_2O + 3CaSO_4.$$

This explains the loss of hardening powers by commercial gypsum (hemihydrate), which when freshly burned requires more water to harden than does gypsum which has been allowed to stand for some time. The influence of other compounds upon the rate at which this reaction takes place has been investigated by Rohland,[a] but the results of this work are of a qualitative nature.

Still a second modification of anhydrous calcium sulphate is known—the anhydrite found in nature. By long contact of the soluble anhydrite with boiling water van 't Hoff and Weigert[b] have shown that the solubility decreases, but that there is no change in the chemical composition of the solid phase, as the natural anhydrite is more stable than either the soluble anhydrite or the hemihydrate. The temperature of formation from gypsum must be lower than that of either of the other forms, and consequently the vapor pressure of gypsum in contact with natural anhydrite will be greater than that of gypsum in contact with either of the other modifications.

The vapor pressures at which gypsum changes to the natural anhydrite at different temperatures has been given in Table II. The temperature at which this vapor pressure curve cut the vapor pressure curve of water is 66° C., the temperature at which anhydrite, gypsum, and aqueous solution exist in equilibrium. The temperature at which the former vapor pressure curve cuts that for saturated sodium chloride solution is the temperature of the transformation in the presence of this solution. From the diagram (fig. 1) this is found to be at 30° and the pressure is 24 mm. This agrees with dilatometric measurements made at temperatures in this neighborhood. Above this temperature there was an expansion because the products of the change (anhydrite and solution) occupy greater volume than gypsum; below 30° the reverse changes take place. This is also in harmony with the statement of Fassbender[a] that gypsum is the stable phase in equilibrium with cold saturated sodium chloride solutions, while at higher temperatures anhydrite is the stable phase. The results of Hoppe-Seyler,[b] who obtained natural anhydrite at 125° from saturated sodium chloride solution, are not inconsistent with the results of van 't Hoff, Hinrichsen and Weigert. Using a saturated sodium bromate solution the inversion temperature was found by the latter investigators to be 50.2° C. at a pressure of 83.3 mm. The formation of natural anhydrite at ordinary temperatures by saturated calcium chloride and saturated magnesium chloride solutions, as given by Brauns,[c] is in accord with the above observations. Struve[d] has found that in the presence of concentrated sulphuric acid (of which the vapor pressure is very low) the stable solid phase is the natural anhydrite.

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[a] Zeit. anorg. Chem., 35, 194 (1903).

[b] Sitzungsber. Akad. Wiss. Berlin, 1901, 1140.

To summarize the data upon the changes of the different forms of calcium sulphate, there exist but two forms of this salt which are stable in the presence of any solution—gypsum and natural anhydrite—and the conditions under which one or the other form is stable depend upon the temperature and the nature of the solution with which it is in contact. For a calcium sulphate solution this inversion temperature is about 66°, for a saturated sodium bromate solution the temperature is 50°, and for a saturated sodium chloride solution the temperature is 30°. To determine the inversion temperature for any other salt solution it is necessary merely to draw its vapor pressure curve, and assuming that the calcium sulphate which goes into solution does not materially alter this vapor pressure, the point of intersection of this curve with the curve representing equilibrium conditions between natural anhydrite and gypsum will indicate the proper temperature. The other two forms—soluble anhydrite and the hemihydrate—are always metastable, and the conditions under which gypsum changes into either one will be determined from the intersection of the proper vapor pressure curves.

CALCIUM SULPHATE IN NATURE.

The facts that natural anhydrite is more stable than soluble anhydrite and that soluble anhydrite is more stable than the hemihydrate are of great importance in explaining the existence in nature of the natural anhydrite. As the temperature at which gypsum changes into the natural anhydrite was formerly considered to be over 150° C., there seemed to be no explanation of the presence of anhydrite in natural deposits. This temperature has been shown to be 66° in the presence of water, and even as low as 30° in contact with saturated sodium chloride solution. Further, it is highly probable that anhydrite has been deposited from solutions which have contained large quantities not only of common salt but also of other very soluble salts, all of which have tended to depress the inversion temperature. Just as the presence of anhydrite in salt regions was inexplicable, so the absence of the hemihydrate proved very perplexing. This, however, agrees perfectly with the data which have been determined by van 't Hoff and his coworkers. The hemihydrate and soluble anhydrite are under all conditions metastable in contact with solutions and tend to change into the stable forms natural anhydrite and gypsum.

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[a] Ber., **11**, 1968 (1878).

[b] Ann. Phys., **127**, 161 (1866).

[c] Neues Jahrb. f. Min., 1894 (2), 257.

[d] Zeit. Chem., **5**, 324 (1869).

In this connection it is interesting to note that a state of affairs somewhat similar to that just described for calcium sulphate exists in the case of the modifications of calcium carbonate, calcite, and aragonite. Becquerel[a] has observed that in the presence of a fairly concentrated potassium carbonate solution, a crust of aragonite crystals were deposited after several years' contact. Calcium carbonate when deposited from solutions containing sodium chloride or ammonium chloride below 30° has been found by Watson[b] to crystallize as calcite, but above that temperature as aragonite.

The only two modifications of calcium sulphate found in nature are, as might be expected, natural anhydrite and gypsum, the stable forms. Both these minerals are found in large quantities, widely distributed. Gypsum[c] occurs near Lockport, at Camillus, Manlius, and Troy, N. Y.; in Davidson County, Tenn.; at St. Marys, Md.; at Poland and Canfield, Ohio; in Mammoth Cave, Kentucky; in New York State from Syracuse to the western extremity of Genesee County; in Michigan, Illinois, Virginia, Tennessee, Kansas, Arkansas, Texas, Iowa, Nevada, California, Wyoming, Oregon, Colorado, Montana, Dakota, Oklahoma, New Mexico, and Arizona; also at Hillsboro, New Brunswick, and in Hants, Colchester, and other districts in Nova Scotia. In Europe gypsum is found at Bex in Switzerland, at Hall in the Tyrol, Sicily, at Montmartre near Paris, at Castelino near Leghorn, and in many other localities. Anhydrite is found with gypsum at Lockport, N. Y.; near Windsor, Nova Scotia, and at Hillsboro, New Brunswick. It has been discovered also in salt mines near Hall in Tyrol, and at Bex, Switzerland; at Sulz on the Neckar, Würtemberg; Himmelsberg near Ilfeld; Bleiberg, Carinthia; Lüneburg, Hanover; Lauterberg in the Harz; Kapnik, Hungary; Ischl, Austria; Aussee, Styria; Berchtesgaden, Bavaria; at Rienthal and other localities in the Alps, and at Stassfurt.

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[a] Compt. rend., **76**, 245 (1873).

[b] Chem. News, **63**, 109 (1891).

[c] See Dana, A System of Mineralogy (1868), pp. 621, 637; Adams et al., Gypsum Deposits of the United States, U. S. Geol. Survey Bul. No. 223 (1904).

The conditions under which the gypsum and anhydrite have been deposited are indicated in the preceding chapter. A deposition of calcium sulphate from a strong solution of salts is in the form of anhydrite, and a crystallization at higher temperatures from more dilute solutions also yields anhydrite. Anhydrite is the first compound crystallizing out of the evaporating saline solution from which the Stassfurt salt beds resulted. Bischof[a] has divided these beds vertically into four regions, of which the first is known as the anhydrite region.[b] After the deposition of anhydrite and its exposure to weathering influences, or after the mother liquor has for any reason been drained off,[c] there is a tendency to form gypsum. This formation has been observed in process[d] at Bex in Switzerland, where extensive beds are altered in part to gypsum to a depth of 60 to 100 feet, below which unaltered anhydrite is found. Sometimes specimens of anhydrite are altered between the folia or over the exterior. These facts have long been known, as is shown by the following quotation from Bischof's Chemical and Physical Geology.[e]

> When the gypsum has been examined at somewhat greater depths it is found to be no longer hydrated, but occurs in the anhydrous state as anhydrite. This leads to the conjecture that gypsum is in great part formed from anhydrite by contact with the atmosphere. It is not surprising that this action should extend to greater depths in some places when the masses of rock are much fissured and torn asunder, thereby allowing a free ingress to the atmospheric air.
>
> Blum mentions several places where a conversion of anhydrite into gypsum has taken place, and, among others, the valley of Canaria, in Switzerland. In this locality the anhydrite, where it comes to the surface, is converted over a wide extent into gypsum. At Bex, according to the observations of V. Charpentier, all the gypsum which occurs upon the surface has arisen by conversion of anhydrite. There are pieces, indeed, in which the transition can be traced. The pure anhydrite is found always in the inner parts of the rock or in the steep parts where, by means of landslides, the interior of the rock has been exposed. Similar appearances have been observed by Alberts in the *muschelkalk* of the southwest of Germany.
>
> Anhydrite takes up, during its conversion into gypsum, about one-fourth its weight of water. If its specific gravity were not thereby altered, its volume would only undergo an increase proportional to the amount of water taken up. But since the

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[a] See Dana, loc. cit., p. 641.

[b] The following description of the Stassfurt salt deposits is from Ries's "Economic Geology of the United States" (1905), p. 127.

At the bottom is the main bed of rock salt, which is broken up into layers 2 to 5 inches thick by layers of anhydrite. Above this comes 200 feet of rock salt, with which are mixed layers of magnesium chloride and polyhalite. Resting on this is 180 feet of rock salt, with alternating layers of sulphates, chiefly kieserite, the sulphate of magnesia. These layers are about 1 foot thick. Lastly, and uppermost, is a 135-foot bed consisting of a series of reddish layers of rock salts of magnesia and potassium, kainite, kieserite, carnallite, tachydrite, as well as masses of snow-white boracite.

[c] This has actually taken place in some of the gypsum deposits of Kansas. See Haworth, Mineral Resources of Kansas, 1897, p. 61.

[d] See Dana, loc. cit., p. 622.

[e] 1853 ed., p. 422.

specific gravity of gypsum is only four-fifths of that of anhydrite, the volume must on this account, also, increase during the conversion. The expansion of anhydrite during its transformation into gypsum must, therefore, be very considerable. Its effects are very well seen in old galleries of mines which have been formed in anhydrite. In these there occur parts of the walls so loosened that the miners can scarcely pass.

SOLUBILITY OF CALCIUM SULPHATE IN WATER.

The solubility of gypsum in water has been investigated by many experimenters. The experimental results published prior to 1870 are, however, of little value, for they do not agree with one another, nor do they agree with measurements made more recently and with greater precision. The first series of accurate results on the solubility of gypsum in water was obtained by Marignac,[a] who worked with much greater care than the earlier experimenters.[b] His results agree quite closely with the more modern results. Droeze[c] several years later determined the solubility of gypsum at temperatures ranging from 0° to 35° C., over which Marignac had obtained but few measurements. By the method of least squares Droeze calculated the most probable values for the solubility, taking into consideration his own and Marignac's results. These values are given in Table V.

TABLE V.—*Number of parts of water sufficient to dissolve one part of gypsum at different temperatures, as determined by Droeze and Marignac.*

Droeze.		Marignac.			
Temperature.	Parts water.	Temperature.	Parts water.	Temperature.	Parts water.
° C.		° C.		° C.	
0	415	40	369	80	404
5	412	45	372	85	415
10	407	50	374	90	427
15	398	55	375	95	440
20	371	60	377	100	455
25	365	65	381		
30	361	70	387		
35	359	75	395		

The results of Raupenstrauch,[d] published in 1885, also agree very well with the latest results on this subject. The next series of measurements were by Goldammer,[e] who found that complete saturation could be effected by shaking precipitated gypsum with water for five minutes. Hulett and Allen[a] have determined the solubility of gypsum with great precision and their results have an especial value, as will be shown presently. The solubility at 25° of powdered calcium sulphate and gypsum from a number of sources has been determined in this laboratory[b] with concordant results. The results of these investigations have been recalculated in order to compare the data, and the only basis on which such a comparison could be made was to find the ratio of parts of gypsum ($CaSO_4$) to water. All the earlier work gives the results in this form without recording the densities of the solutions.

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[a] Arch. Sciences phys. et nat., Genève, 1873, No. 190.

[b] Henry, Jour. Phar., **12**, 31 (1826); Poggiale, Ann. Chim. Phys. (3), **8**, 463 (1843); Lassaigne, Jour. Phar. (3), **5**, 301 (1844); Buchholz and Giese, Gmelin's Handbuch., 5th edn. (1853), p. 186; Tipp, Vierteljahrschrift f. prakt. Pharmacie, **3**, 506 (1854); N. Jahrb. Phar., **2**, 375 (1854); Bischof, Lehrbuch Chem. Phys. geol., 2d edn., II, p. 184; de Boisbaudran, Ann. Chim. Phys. (4), **9**, 173 (1868); (5), **3**, 477 (1874); Church, Zeit. Chem., **3**, 735 (1867); Bul. Soc. Chim. (2), **9**, 308 (1867); Cossa, Gazz. chim. ital., 1873, 135, et al.

[c] Ber., **10**, 330 (1877).

[d] Monatsh., **6**, 563 (1885).

[e] Phar. Centralhalle, **29**, 193 (1888).

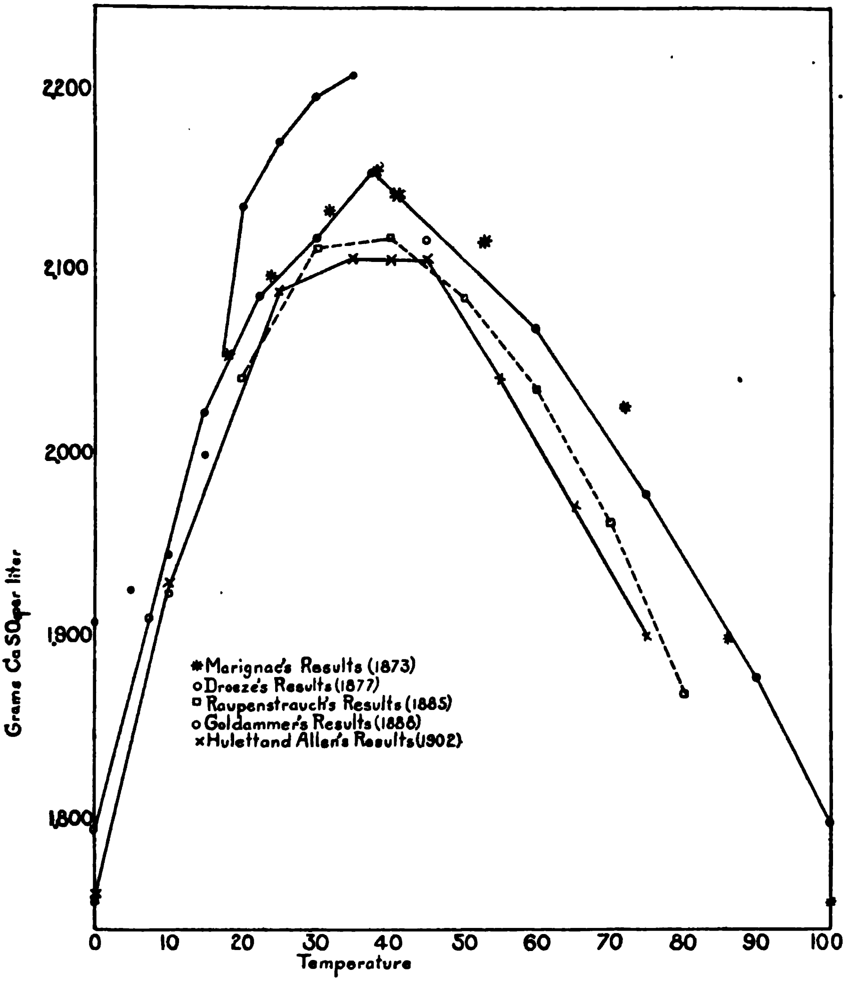

FIG. 4.—Solubility of calcium sulphate in water (0° to 100° C.).

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[a] Jour. Am. Chem. Soc., **24**, 667 (1902).

[b] Cameron and Breazeale, Jour. Phys. Chem., **7**, 571 (1903).

Hulett and Allen's results are given as grams of $CaSO_4$ per 100 c. c. of solution and from the density determinations the number of grams of $CaSO_4$ per 100 grams of water have been calculated. The results of Hülett and Allen are given in the foregoing diagram (fig. 4) taken from their paper.

The reason for the wide discrepancies in all the earlier work seems to be the tendency to form solutions supersaturated with respect to the solid phase $CaSO_4.2H_2O$. This may be attributed to two causes—the uncertainty in the earlier work as to the nature of the solid phase in contact with the solution, and the variation of the solubility of calcium sulphate depending on the size of the particles of the solid phase.

It is generally true that when a salt forms several hydrates the hydrate in stable equilibrium with a solution of the salt is that one which exists in equilibrium with the weakest solution. For instance, below 33° C. a solution saturated with $Na_2SO_4.10H_2O$ is less concentrated than the solution saturated with respect to the anhydrous salt, and therefore the hydrated salt is the stable compound. Above 33° the reverse is the case and the anhydrous salt is the stable form in contact with a solution. In the present case of calcium sulphate, there are (1) the anhydrous salt $CaSO_4$ (anhydrite), (2) the hemihydrate $2CaSO_4.H_2O$, and (3) the dihydrate $CaSO_4.2H_2O$ (gypsum).

TABLE VI.—*Solubility of calcium sulphate in water.*

Temperature.	Grams $CaSO_4$ per 1,000 grams water, according to—						
	Marignac.	Droeze.	Raupenstrauch.	Goldammer.	Hulett and Allen.	Böttger.[a]	Cameron and Breazeale.
°C.							
0	1.906	1.906	1.756	1.795	1.759	....	....
5	....	1.924	....	....	....	....	....
7.5	....	....	....	1.909	....	....	....
10	....	1.943	1.922	....	1.928	....	....
15	....	1.997	....	2.020	....	....	....
18	2.051	....	....	....	2.019	....	....
20	....	2.132	2.039	....	....	2.036	....
22.5	....	....	....	2.083	....	....	....
24	2.093	....	....	....	....	....	....
25	....	2.167	....	....	2.086	....	2.126
30	....	2.192	2.109	2.114	2.098	....	....
32	2.129	....	....	....	....	....	....
35	....	2.203	....	....	2.104	....	....
37.5	....	....	....	2.150	....	....	....
38	2.150	....	....	....	....	....	....
40	....	....	2.115	....	2.102	....	....
41	2.138	....	....	....	....	....	....
45	....	....	....	2.114	2.103	....	....
50	....	....	2.083	....	....	....	....
53	2.112	....	....	....	....	....	....
55	....	....	....	....	2.038	....	....
60	....	....	2.032	2.066	....	....	....
65.3	....	....	....	....	1.969	....	....
70	....	....	1.960	....	....	....	....
72	2.023	....	....	....	....	....	....
75	....	....	....	1.976	1.898	....	....
80	....	....	1.868	....	....	....	....
86	1.898	....	....	....	....	....	....
90	....	....	....	1.876	....	....	....
99	1.754	....	....	....	....	....	....
100	....	....	....	1.798	....	....	....

[a] Zeit. phys. Chem., **46**, 603 (1903).

The boiling point of the solution in equilibrium with gypsum has been determined by van 't Hoff and Armstrong[a] as 101.45° C. at atmospheric pressure. The vapor pressure curves for gypsum and for the solution saturated with gypsum have been determined by these experimenters, and thus the transition temperature of gypsum has been found. For stable equilibrium the vapor pressure of the solid hydrate must be less than the vapor pressure of the solution in equilibrium with it. The stable hydrate under these conditions is that hydrate which has the highest vapor pressure or the hydrate with the greatest degree of hydration, the vapor pressure being, of course, lower than that of the solution. The vapor pressure of gypsum becomes greater than that of the solution in equilibrium with it at 107° C., and therefore there is a change in the solid phase, the lower hydrate $2CaSO_4.H_2O$ making its appearance. The effect of other salts in solution upon the transition temperature will be considered in another place. The rate at which anhydrite passes into aqueous solution has been shown by McCaleb[b] to be much slower than that at which gypsum goes into solution, although its solubility at lower temperatures must be greater, as gypsum is the stable phase and therefore the least soluble. This fact explains the extremely slow rate at which anhydrite changes over into gypsum in the presence of water. The velocity at which the final equilibrium is reached, when the hemihydrate is shaken with water, seems to be rather slow, and consequently, unless equilibrium is attained, the observed concentration of the solution is greater than that of the solution saturated with gypsum. This tendency to supersaturation has been found by Goldammer[c] to be greatest at ordinary temperatures. Gypsum which had been dried at 120°–130° to constant weight and dissolved in water has been found by Erlenmeyer[d] to possess a high solubility, which decreased after some days to the normal solubility of gypsum in water. His results follow:

10 minutes after adding burnt gypsum to water, 1 part $CaSO_4$ in 82 parts water.
20 minutes after adding burnt gypsum to water, 1 part $CaSO_4$ in 170 parts water.
2 days after adding burnt gypsum to water, 1 part $CaSO_4$ in 391 parts water.
14 days after adding burnt gypsum to water, 1 part $CaSO_4$ in 495 parts water.

During this time there has been a change in the crystalline structure of the solid from burnt gypsum to that of ordinary gypsum. Practically the same results have been obtained by Marignac[e] and by Potilitzin.[f]

The second reason for the abnormally high solubility found for gypsum by the earlier experimenters has been demonstrated by Hulett and Allen.[a] The solubility of gypsum depends on the size of the particles in contact with the solution, particles less than 0.3 micron in size giving a solution 20 per cent more concentrated than a solution in equilibrium with massive gypsum. This is attributed to the influence of surface tension on the solubility, for Hulett[b] has shown that the energy on the surface bounding a solid and its saturated solution is a measurable factor of the solubility. The concentration of the solution in equilibrium with a curved surface is different from that in equilibrium with a plane surface, a convex surface having a greater solubility and a concave one a less solubility than a plane surface. A finely powdered surface will, therefore, possess a greater solubility than the same substance in mass. In order to obtain a "normally saturated solution"—i. e., a solution in equilibrium with a plane surface of the solid—it is sufficient to allow all the finer particles to dissolve, as they are more soluble, and then to precipitate again on the less soluble larger pieces.

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[a] Sitzungsber. Akad. Wiss. Berlin, 1900, 559.

[b] Am. Chem. Jour., **11**, 31 (1889).

[c] Phar. Centralhalle, **29**, 193, 215 (1888).

[d] Verhandl. Math. phys. Classe K. bayer. Acad., 1872, 269.

[e] N. Arch. ph. nat., Genève, **48**, 120 (1873).

[f] Jour. Russ. Phys. Chem. Soc., **25**, 207 (1893).

The experiments of Hulett and Allen, in which water was made to flow over plates of gypsum, must be taken as giving most nearly the true value of the solubility, although not the value which would be obtained under ordinary conditions. The curve of solubilities found by Hulett and Allen shows a maximum solubility at 40° C. The reasons for this maximum have been sought by these authors, and it has been connected with the change in the heat of solution at this temperature; but the reason why either of these correlated quantities, heat of solution and solubility, should undergo a change is still unexplained. It was thought that there was a change of solid phase at this temperature, but the vapor pressure curve of gypsum shows no break up to 107° C., at which temperature gypsum changes to the hemihydrate. This regularity excludes the explanation of the appearance of a new solid phase.

SOLUBILITY OF CALCIUM SULPHATE IN AQUEOUS SOLUTIONS.

The solubility of calcium sulphate in different solutions has been measured by a large number of investigators, and it has been considered advisable to collect all the available data on this subject for the sake of comparison. As there is a general theory that the effect of another substance in solution which yields a common ion should depress the solubility, it is convenient to divide the different solutions into three general classes: First, containing solutes which yield an ion present in gypsum solutions; second, containing solutes which are electrolytes and which contain no ion in common with gypsum; and third, containing nonelectrolytes. The first class has been subdivided into two divisions, (*a*) sulphates and (*b*) calcium salts.

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[a] Loc. cit.

[b] Zeit. phys. Chem., **37**, 385 (1901). The effect of the size of solid particles has been shown by Ostwald [Zeit. phys. Chem., **34**, 496 (1900)] to have an influence on the solubility. Thus he found that the solubility of very finely divided mercuric oxide is greater than that of coarse mercuric oxide.

SOLUBILITY OF CALCIUM SULPHATE IN SULPHATE SOLUTIONS.

Ammonium sulphate:

Before any measurements were recorded on the solubility of gypsum in solutions of ammonium sulphate a double compound of these sulphates $(NH_4)_2SO_4.CaSO_4.H_2O$ had been observed by Popp[a] and by Fassbender,[b] who obtained it by dissolving 285 grams of ammonium sulphate in 800 c. c. of water and saturating the solution with gypsum, and after evaporation to 500 or 600 c. c. filtering off the mother liquor at 40° to 50° C. The double salt is isomorphic with the double potassium calcium sulphate. Ditte[c] obtained the double salt from a concentrated solution after allowing it to stand for some days.

Droeze[d] was the first to make any determinations of the solubility of gypsum in solutions of ammonium sulphate. A saturated solution of ammonium sulphate at 8.5° to 9° C. will dissolve 3.06 grams gypsum per liter, and a solution of one-seventh saturated at 13.5° will dissolve 2.709 grams of gypsum per liter. A more complete series of determinations has been made by Cohn.[e] From the diagram it will be seen that the solubility of calcium sulphate decreases with increasing amounts of ammonium sulphate in the solution, but at higher concentrations the solubility increases. The following table recalculated from Cohn's results gives the percentage of each salt compared to water at 22.5° C.

TABLE VII.—*Solubility of calcium sulphate in ammonium sulphate solutions at 22.5°.*

Parts $(NH_4)_2SO_4$ per 100 parts solution.	Parts $CaSO_4$ per 100 parts solution.	Parts $(NH_4)_2SO_4$ per 100 parts solution.	Parts $CaSO_4$ per 100 parts solution.
3.236	0.16209	18.581	0.31545
7.976	.20509	22.031	.33117
11.725	.25299	25.310	.35585
14.964	.28602	28.636	.36901

The diagram (fig. 7) shows that the solubility curve goes through a minimum, but the data are insufficient to give the concentration at this point. There seems to be no doubt that the curve is continuous, and hence no new solid phase has appeared at this temperature. It must be remembered that the double sulphate was obtained by Fassbender above 40°, and hence the double sulphate makes its appearance between 22° and the temperature at which Cohn worked.

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[a] Ann. Chem. Phar. Suppl., **8**, 1 (1870–72).

[b] Ber., **9**, 1358 (1876); **11**, 1968 (1878).

[c] Compt. rend., **84**, 86 (1877).

[d] Ber., **10**, 330 (1877).

[e] Jour. prakt. Chem., **143**, 43 (1887).

A similar result has recently been obtained by Sullivan,[a] who does not, however, refer to Cohn's work. Sullivan's experiments were conducted at 25° C., and the curve is similar to that obtained by Cohn. The solubility of gypsum at first decreases to a minimum, and then increases with increasing amounts of ammonium sulphate in the solution. At this temperature Sullivan's results indicate that the double salt does not appear. The results, which are given in mols per liter, have been changed into grams per liter; and as the densities have also been given, it is possible to calculate grams of salt per 100 grams of water, and these results have been plotted in the diagram. Sullivan's results are as follows:

TABLE VIII.—*Solubility of calcium sulphate in ammonium sulphate solutions at 25° C.*

Density at 25°.	$(NH_4)_2SO_4$ per 100 c. c. solution.	$CaSO_4$ per 100 c. c. solution.	Density at 25°.	$(NH_4)_2SO_4$ per 100 c. c. solution.	$CaSO_4$ per 100 c. c. solution.
	Grams.	*Grams.*		*Grams.*	*Grams.*
0.99911	0	0.2083	1.00841	0.8266	0.1440
.99911	.0129	.2043	1.00817	1.6532	.1455
.99920	.0258	.1996	1.01763	3.3065	.1617
.99946	.1033	.1807	1.05344	6.6130	.2330
.99995	.2067	.1658	1.10324	13.2259	.3330
1.00104	.4133	.1540	1.19149	26.4578	.4500

The solubility of gypsum has been determined by Bell and Taber[b] at 50° with the following results:

TABLE IX.—*Solubility of calcium sulphate in solution of ammonium sulphate at 50° C.*

Density, 50°.	$(NH_4)_2SO_4$ per liter.	$CaSO_4$ per liter.	Density, 50°.	$(NH_4)_2SO_4$ per liter.	$CaSO_4$ per liter.
	Grams.	*Grams.*		*Grams.*	*Grams.*
....	0	2.168	1.1968	416.0	5.345
1.0026	15.65	1.609	1.2043	428.4	4.632
1.0113	30.67	1.750	1.2187	479.4	3.524
1.0440	91.6	2.542	1.2437	540.8	2.152
1.0819	160.4	3.402	1.2480	558.0	1.986
1.1108	221.6	4.068	1.2502	564.0	1.98
1.1385	280.6	4.690	1.2508	566.0	1.08
1.1653	340.6	5.084	1.2510	566.7	0

The plot of these results shows breaks at 416 grams $(NH_4)_2SO_4$ per liter and at 564 grams $(NH_4)_2SO_4$ per liter. Between these concentrations the solid phase was a double salt of ammonium sulphate and calcium sulphate of the formula $CaSO_4.(NH_4)_2SO_4.2H_2O$.

Potassium sulphate.

A double salt of potassium and calcium sulphates, $CaSO_4.K_2SO_4.H_2O$, has been observed as a by-product in the manufacture of tartaric acid by Philips,[c] Rose,[d] Struve,[e] Schott,[f] Fassbender,[g] Ditte,[h] Hannay,[i]

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[a] Jour. Am. Chem. Soc., **27**, 529 (1905).

[b] Jour. Phys. Chem., **10**, 119 (1906).

[c] Jour. Chem. Soc., **3**, 348 (1851).

[d] Ann. Phys., **93**, 1 (1854).

[e] Zeit. Chem., **5**, 323 (1869).

[f] Dingl. Poly. Jour., **196**, 357 (1870).

[g] Ber., **9**, 1358 (1876).

[h] Compt. rend., **84**, 86 (1877).

[i] Chem. News, **34**, 256 (1876).

Grosjean,[a] and others, and it has been prepared in several different ways. Rose obtained it by mixing solutions of potassium sulphate and calcium sulphate; Struve by the action of KNO_3, KCl, or KI solutions on gypsum solutions, although Fassbender doubts whether it can be prepared in this way from the chloride solution. The latter has also described a compound to which he gives the formula $CaSO_4.K_2SO_4.2KCl.H_2O$, but it seems more probable that this is a mixture of the double salt and potassium chloride. The double salt has been shown to be identical with the double sulphate found together with sylvine, KCl, in Kalusz, and formerly called kaluszite. Later, on account of this relation to polyhalite, it was called syngenite. Van 't Hoff and Wilson[b] have determined the composition of the solution in equilibrium with both calcium sulphate and syngenite at 25° and have applied these data to the determination of the conditions governing the formation of syngenite.

A second double compound of the formula $2CaSO_4.K_2SO_4.3H_2O$ and also $2CaSO_4.RbSO_4.3H_2O$ is given by Ditte.[c] The solution in equilibrium with the double salt and with solid K_2SO_4 has about the same content of K_2SO_4 per liter as the solution saturated with the double compound and gypsum. The range of concentration in equilibrium with the double salt is therefore very limited, and in contact with water the salt decomposes to the single sulphates. In a later paper Ditte[d] has recorded the double sulphate $CaSO_4.K_2SO_4.4H_2O$. The conditions for the formation of potassium pentacalcium sulphate $K_2SO_4.5CaSO_4.H_2O$, which is recorded by van 't Hoff,[e] are given in another place.

The only determinations of the solubility of gypsum in different potassium sulphate solutions before 1904 were by Droeze,[f] who found that at 13.5° C. a saturated solution of K_2SO_4 would dissolve 0.043 gram gypsum per 100 c. c., and that a solution one-fifth saturated would dissolve 0.1505 gram gypsum per 100 c. c.

A series of determinations have been made by Cameron and Breazeale[g] by adding an excess of gypsum to solutions of potassium sulphate and by adding syngenite to solutions of potassium sulphate. The following data were obtained at 25° C. The work was done in two series of experiments, series B being somewhat more carefully planned.

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[a] Dingl. Poly. Jour., **250**, 371 (1883).

[b] Sitzungsber. Akad. Wiss. Berlin, 1900, 1142.

[c] Compt. rend., **79**, 215, 956, 1254 (1874).

[d] Compt. rend., **126**, 694 (1898).

[e] Sitzungsber. Akad. Wiss. Berlin, 1904, 935.

[f] Ber., **10**, 330 (1877).

[g] Jour. Phys. Chem., 8, 335 (1904).

TABLE X.—*Solubility of calcium sulphate in solutions of potassium sulphate at 25° C.*

Series A.			Series B.		
Weight of 1,000 c. c. of solution.	Quantity K_2SO_4 per liter.	Quantity $CaSO_4$ per liter.	Weight of 1,000 c. c. of solution.	Quantity K_2SO_4 per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1,003.61	4.88	1.601	1,003.80	5.09	1.563
1,007.54	9.86	1.504	1,007.54	5.85	1.446
1,015.54	19.71	1.534	1,015.15	19.57	1.485
1,022.82	29.72	1.582	1,022.86	28.35	1.553
1,032.18	41.91	1.073	1,023.64	30.66	1.587
1,046.28	54.25	.551	1,024.14	31.15	1.549
1,060.35	80.04	.398	1,026.92	35.19	1.257
1,075.54	99.68	.252	1,027.32	35.79	1.213
			1,030.62	40.53	.970
			1,072.41	96.00	.257

Syngenite was prepared by dissolving 120 grams of potassium sulphate in 1,000 c. c. of water, and to this was added a solution containing 20 grams of anhydrous calcium chloride in 100 c. c. of water. After standing some time the precipitated magma was washed with 85 per cent alcohol, and finally with ordinary alcohol, until free from chlorides. This syngenite was then treated in the manner above described for the calcium sulphate in potassium sulphate solution. The concentrations of the resulting solutions in potassium sulphate and calcium sulphate are given in Table XI.

TABLE XI.—*Solubility of syngenite in solutions of potassium sulphate.*

Weight of 1,000 c. c. of solution.	Quantity K_2SO_4 per liter.	Quantity $CaSO_4$ per liter.	Weight of 1,000 c. c. of solution.	Quantity K_2SO_4 per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Gram.*
1,013.08	16.31	1.495	1,036.82	46.99	0.810
1,015.78	19.87	1.529	1,058.10	75.45	.451
1,020.01	25.01	1.537	1,085.91	112.87	.330
1,024.54	30.83	1.565			

In the first four determinations the syngenite was completely decomposed, and gypsum was formed and remained as solid phase; the corresponding amounts of potassium sulphate passed into solution and increased the concentration with respect to this salt. Beyond the fourth determination the concentration with respect to potassium sulphate was sufficient for the existence of the syngenite in the solid phase.

From the accompanying diagram (fig. 7) it is evident that we are dealing here with two intersecting curves. The upper part of these two curves gives the solubility of calcium sulphate in solutions of potassium sulphate of varying concentrations, and the lower curve the solubility of the syngenite, which forms in solutions of concentrations of potassium sulphate greater than about 32 grams per liter. The first curve shows the conditions of concentration for equilibrium between potassium sulphate and calcium sulphate when the solution is in contact with calcium sulphate or gypsum as solid phase, and the second curve the conditions with syngenite as solid phase. The intersection of the two curves gives the stable inversion point where the solution is in equilibrium with both gypsum and syngenite as solid phases. This inversion point is somewhat lower in respect to calcium sulphate than was found by van 't Hoff and Wilson,[a] who give the composition of the solution in equilibrium with the syngenite and potassium sulphate to be 30.8 grams K_2SO_4 and 1.9 grams $CaSO_4$ per liter. To test further the position of the inversion point the procedure followed by these investigators was used, and the results obtained show that the values for the inversion point at 25° C., as found by extrapolation on the curves, are substantially correct:

Procedure.	Grams per liter of solution.	
	K_2SO_4.	$CaSO_4$.
By direct determination	32.47	1.582
By extrapolation	32.00	1.585

Potassium sulphate is employed as the source of potassium in the manufacture of caustic potash. Lime is added to solutions of potassium sulphate, and at the lower concentrations the resulting products are gypsum and caustic potash,

$$Ca(OH)_2+K_2SO_4+2H_2O\rightleftarrows CaSO_4.2H_2O+2KOH.$$

This reaction has been studied by Herold[b] to find out the most efficient temperature and concentration for the production of alkali, and in his investigations at the lower concentration the condition has been imposed that the solution always contains solid calcium hydroxide and solid gypsum. At the higher concentrations gypsum no longer exists in equilibrium with the solutions, syngenite ($CaSO_4.K_2SO_4.H_2O$) appearing,

$$Ca(OH)_2+2K_2SO_4+H_2O\rightleftarrows CaSO_4.K_2SO_4.H_2O+2KOH.$$

Under these conditions the composition of the solutions have been found, calcium hydroxide and syngenite always being present as solids. Unfortunately the composition of the solutions were not completely determined, only the concentration of hydroxyl (OH) and of the sulphion (SO_4) having been found. No data regarding the concentration of the calcium or of potassium are recorded. The equilibrium has been approached from two directions, for calcium hydroxide has been added to solutions of potassium sulphate and gypsum has been added to solutions of caustic potash. The following table gives the concentration of the solutions, expressed in terms of millimols per liter.

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[a] Sitzungsber. Akad. Wiss. Berlin, 1900, 1142.

[b] Zeit. Elektrochem., **11**, 417 (1905).

TABLE XII.—*Concentration of solutions in equilibrium with calcium hydroxide and either gypsum or syngenite.*

Temperature.	Starting from K_2SO_4.		Starting from KOH.	
	Millimols OH.	Millimols SO_4.	Millimols OH.	Millimols SO_4.
°C.				
190	53	27	40	33
	62	69	58	70
	90	180	92	160
	94	249	94	247
150	41	35	45	40
	51	76	68	70
	82	190	91	200
	87	250	98	260
	91	320	106	320
	92		108	
	89		96	
70	40	32	42	25
	53	76	52	68
	70	215	80	210
	79	255	75–76	250
	100	264		
	112	271		
	167	368		
	210	464		
20	60	35	76?	31?
	83	68	89	69
	103	101	116	152
	167	182	119	150
	198	248	120	150
	269	318	118	151
0	64	36	80?	27?
	85	55	92	54
	123	120	123	127
	184	162	124	124
	223	183	124	120
	278	218	120	122
	400	298		

Herold has plotted the concentration with respect to hydroxyl against the concentration with respect to sulphions and at the temperatures 0°, 20°, and 70°. The points lie on two curves, one of which represents solutions in equilibrium with both calcium hydroxide and gypsum, and the other represents solutions in equilibrium with both calcium hydroxide and syngenite. If the composition of these solutions with respect to either calcium or potassium had been determined, it would have been possible to state the best conditions for the largest yield of the desired product, potash.

Several other compounds have been recorded in the literature—$CaNH_4K(SO_4)_2H_2O$ by Fassbender,[a] $K_2CaSO_4CrO_4H_2O$, $K_4CaSO_4(CrO_4)_2$, and $CaK_2Na_2(SO_4)_2CrO_4H_2O$ by Hannay.[b]

Sodium sulphate.

Ditte[c] states that there is no double compound of calcium and sodium sulphates even after standing for some months. The only early measurement on the solubility of gypsum by a sodium sulphate solution is by Droeze,[d] who states that at 10.5° C. a saturated solution of sodium sulphate will dissolve 0.2510 gram of gypsum per 100 c.c.

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[a] Ber., **11**, 1968 (1878).

[b] Chem. News, **34**, 256 (1876).

[c] Compt. rend., **84**, 86 (1876); **126**, 694 (1898).

[d] Ber., **10**, 330 (1877).

The solubility of gypsum in different sodium solutions has been studied by Cameron and Seidell.[a] It was rather to be expected that the two electrolytes would yield a common sulphion, and therefore the solubility of gypsum should decrease as the concentration with respect to sodium sulphate increases. Such was found to be the case up to a concentration of about 17.5 grams per liter of sodium sulphate, when the solubility of the calcium sulphate was about 1.38 grams per liter, or of gypsum 1.745 grams per liter. At this point, as the concentration with respect to sodium sulphate increases, there is a rather sudden change in the direction of the curve and the solubility of the calcium sulphate steadily increases until, in a liter of solution containing 230 grams of sodium sulphate, there will be dissolved 2.5 grams of calcium sulphate—a quantity markedly larger than will be dissolved by pure water. The data obtained for this pair of electrolytes are given in Table XIII.

Table XIII.—*Solubility of calcium sulphate in solutions of sodium sulphate at 22° C.*

Quantity $CaSO_4$ per liter.	Quantity Na_2SO_4 per liter.	Quantity $CaSO_4$ per liter.	Quantity Na_2SO_4 per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*
2.084	0.000	1.841	77.320
1.583	2.771	2.185	133.000
1.433	13.880	2.414	193.800
1.408	16.360	[a] 2.578	[a] 222.580
1.569	39.310		

[a] Both calcium sulphate and sodium sulphate as solid phases were in contact with the solution.

The tentative suggestion is made in this paper that possibly at concentrations with respect to sodium sulphate greater than that at the minimum point, the dissociation of the sodium sulphate takes place in part according to the scheme:

$$\mathrm{Na_2SO_4} = \overset{+}{\mathrm{Na}} + \overset{-}{\mathrm{NaSO_4}}$$

rather than entirely as indicated thus:

$$\mathrm{Na_2SO_4} = \overset{+}{\mathrm{Na}} + \overset{+}{\mathrm{Na}} + \overset{=}{\mathrm{SO_4}}$$

From this point of view one would expect the existence in the solution of a double salt, possibly of the composition $CaSO_4.Na_2SO_4$. Such a salt is the mineral glauberite found in nature. Fritzsche,[b] however, describes a hydrated double sulphate ($CaSO_4.Na_2SO_4.2H_2O$), obtained by heating gypsum with a small amount of water and a large excess of Glauber's salt ($Na_2SO_4.10H_2O$). It was also obtained at ordinary temperatures by adding gypsum to a solution of one part sulphuric acid and two parts saturated sodium sulphate solution. The double sulphate was a well-characterized one, crystallizing in fine needles, which, on heating, quickly lost the contained water, yielding the anhydrous double salt. It was expected, therefore, that this salt, or its hydrate, might be obtained by evaporating solutions of sodium sulphate saturated with respect to calcium sulphate. Such solutions were prepared and were allowed to evaporate spontaneously at room temperature. No evidence of the presence of the double salt, however, could be detected in the residue. It should be remembered that in those areas where this double calcium sulphate has been observed in nature the ground temperatures are frequently very high, and the equilibrium condition of the solution may well be very different from those obtaining at 25° C. The anhydrous double salt has been observed also by Hannay[a] and by Folkard.[b]

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[a] Jour. Phys. Chem., **5**, 643 (1901).

[b] Jour. prakt. Chem., **72**, 291 (1857).

Van 't Hoff and Chiaraviglio[c] have shown that gypsum and the decahydrate of sodium sulphate will form glauberite at 25° C. if the solution be saturated with respect to both these salts and sodium chloride as well. This last substance is commonly, though perhaps not always, found in those areas from which glauberite has been reported as occurring in nature. These authors have also shown that glauberite and gypsum exist together, as solid phases, only when solid sodium sulphate (decahydrate) is not also present. The double salt is not stable in the presence of water alone, and breaks down into the simple salts, gypsum and Glauber's salt.

The following table of the solubility of gypsum in sodium sulphate solutions at 25° C. has been given in a paper published more recently by Cameron and Breazeale.[d] This table shows results similar to those obtained by Cameron and Seidell[e] at 22°. The concentration of the solution in equilibrium with both solid sulphates has been given by Cameron and Brown.[f] In this solution there are 254.6 grams Na_2SO_4 and 2.58 grams $CaSO_4$ per liter at 25° C., while at 22° the concentration as given by Cameron and Seidell[g] is 222.6 grams Na_2SO_4 and 2.58 grams $CaSO_4$ per liter. It seems probable that at different temperatures the double salt might crystallize out, and this point ought to be investigated on account of its importance in several technical operations as well as in geological and soil studies.

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[a] Chem. News, **34**, 256 (1876).

[b] Chem. News, **43**, 6 (1881).

[c] Sitzungsber. Akad. Wiss. Berlin, 1899, 810.

[d] Jour. Phys. Chem., 8. 335 (1904).

[e] Loc. cit.

[f] Jour. Phys. Chem., **9**, 210 (1905).

[g] Loc. cit.

TABLE XIV.—*Solubility of calcium sulphate in solutions of sodium sulphate at 25° C.*

Weight of 1,000 c. c. of solution.	Quantity Na_2SO_4 per liter.	Quantity $CaSO_4$ per liter.	Weight of 1,000 c. c. of solution.	Quantity Na_2SO_4 per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
1,001.26	2.390	1.650	1,079.47	94.220	1.980
1,007.59	9.535	1.457	1,096.47	115.084	2.096
1,011.45	14.132	1.388	1,142.66	146.612	2.234
1,020.46	24.369	1.471	1,176.47	205.105	2.503
1,031.48	36.979	1.563	1,212.00	257.100	2.650
1,039.12	46.150	1.650			

Thallium sulphate.

Ditte[a] states that there is no double sulphate of calcium and thallium.

Magnesium sulphate.

The solubility of gypsum in a saturated magnesium sulphate solution is zero, according to Fassbender.[b] He even proposes a method of precipitating out calcium from solutions containing large quantities of magnesium by saturating the solution with magnesium sulphate. Droeze[c] also finds gypsum to be insoluble in saturated magnesium sulphate solutions, while a solution one-tenth saturated with the latter at 13.5° C. will dissolve only 0.086 gram of gypsum per 100 c. c. Ditte[a] finds that magnesium sulphate forms no double compound with calcium sulphate. Cameron and Bell[d] have determined this solubility at 25° C. from the loss of weight of a selenite plate in equilibrium with a known amount of a magnesium-sulphate solution of known concentration. The results are as follows:

TABLE XV.—*Solubility of calcium sulphate in magnesium sulphate solutions at 25° C.*

Density $\frac{25^\circ}{25^\circ}$	$MgSO_4$ per liter.	$CaSO_4$ per liter.	Density $\frac{25^\circ}{25^\circ}$	$MgSO_4$ per liter.	$CaSO_4$ per liter.	Density $\frac{25^\circ}{25^\circ}$	$MgSO_4$ per liter.	$CaSO_4$ per liter.
	Grams.	*Grams.*		*Grams.*	*Grams.*		*Grams.*	*Grams.*
1.0032	0	2.046	1.0626	64.14	1.608	1.1813	198.8	1.422
1.0055	3.20	1.620	1.0833	85.67	1.617	1.2095	232.1	1.254
1.0090	6.39	1.507	1.1190	128.28	1.627	1.2382	265.6	1.070
1.0118	10.64	1.471	1.1377	149.67	1.597	1.2624	298.0	.860
1.0226	21.36	1.478	1.1479	165.7	1.549	1.2877	330.6	.647
1.0419	42.68	1.558	1.1537	171.2	1.474	1.3023	[a] 355.0	.501

[a] Saturated with $MgSO_4.7H_2O$.

These results do not harmonize with the statements of Fassbender and Droeze, that gypsum is insoluble in saturated magnesium sulphate solution. At the temperature of 25° C. no double salt was observed.

Sulphuric acid.

One determination of the solubility of gypsum in concentrated sulphuric acid (sp. gr. = 1.82) by Struve[e] gives the solubility of $CaSO_4$ as 2.03 parts per 100 parts of the acid. This solubility in different sulphuric acid solutions has been determined by Cameron and Breazeale[a] for three different temperatures, 25°, 35°, and 43°, as given in Table XVI.

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[a] Compt. rend., 84, 86 (1877).

[b] Ber., **9**, 1358 (1876).

[c] Ber., **10**, 330 (1877).

[d] Jour. Phys. Chem., **10**, 210 (1906).

[e] Zeit. Anal. Chem., **9**, 34 (1870).

TABLE XVI.—*Solubility of calcium sulphate in solutions of sulphuric acid.*

Weight of 1,000 c. c. of solution at 25° C.	Quantity, H_2SO_4 per liter.	Quantity, $CaSO_4$ per liter, at—			Weight of 1,000 c. c. of solution at 25° C.	Quantity, H_2SO_4 per liter.	Quantity, $CaSO_4$ per liter, at—		
		25°.	35°.	43°.			25°.	35°.	43°.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
999.1067	0	2.126	....	2.145	1,043.470	75.00	2.841	....	4.146
1,002.493	.48	2.128	2.209	2.236	1,075.613	97.25	2.779	3.606	....
1,002.553	4.87	2.144	2.451	2.456	....	146.01	2.571	3.150	4.139
1,005.091	8.11	2.203	....	2.760	1,113.392	194.70	2.313	....	3.551
1,[illegible]	16.22	2.382	....	3.116	1,141.755	243.35	1.901	....	2.959
1,030.151	48.67	2.727	3.[illegible]	[illegible].843	1,168.148	292.02	1.541	....	2.481

This system presents the remarkable feature that the solubility of calcium sulphate increases with increasing amounts of sulphuric acid up to comparatively high concentrations with respect to the latter. At 25° C. the solubility of calcium sulphate is a maximum with 75 grams H_2SO_4 per liter. The solubility then decreases with stronger acid solutions.

Mixtures of potassium and magnesium sulphates.

The effect of mixtures of potassium and magnesium sulphates in solution have been studied by Basch[b] under van 't Hoff's direction. In this work, the composition of solutions, saturated with a maximum number of solids, or to use van 't Hoff's term, *constant solutions*, have been determined at 25°. At this temperature the possible solid phases are gypsum, potassium sulphate, magnesium sulphate ($MgSO_4.7H_2O$), syngenite ($K_2SO_4.CaSO_4.H_2O$), schönite ($MgSO_4.K_2SO_4.6H_2O$), and polyhalite ($K_2SO_4.2CaSO_4.MgSO_4.2H_2O$). Table XVII gives the composition of the solution with respect to potassium sulphate and magnesium sulphate, the concentration of calcium being so small in most cases as to be undeterminable in the presence of large amounts of magnesium. Geiger,[c] also working under van 't Hoff's direction, has studied the system composed of the same sulphates at 83°. (See Table XVII.) At this temperature the possible solid phases are anhydrite, potassium sulphate, kieserite ($MgSO_4.H_2O$), langbeinite ($2MgSO_4.K_2SO_4$), leonite ($MgSO_4.(Na,K)_2SO_4.4H_2O$), syngenite ($K_2SO_4.CaSO_4.H_2O$), pentacalcium sulphate ($5CaSO_4.K_2SO_4.H_2O$), polyhalite ($2CaSO_4.K_2SO_4.$-$MgSO_4.2H_2O$), and krugite ($4CaSO_4.K_2SO_4.MgSO_4.2H_2O$). In the accompanying diagrams (figs. 5 and 6) there have been plotted the concentration in molecules of potassium sulphate and of magnesium sulphate per 1,000 molecules of water. The fields in the plates show the conditions of concentration under which each of the possible solid phases may exist. For instance, it will be seen that at 25° the triple sulphate, polyhalite, exists in equilibrium with a solution within very narrow limits of concentration, while the salt syngenite is the stable phase over a very much greater range of concentrations. At 83°, however,

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[a] Jour. Phys. Chem., 7, 571 (1903).

[b] Sitzungsber. Akad. Wiss. Berlin, 1900, 1084; Künstliche Darstellung und Bildungsverhältnisse des Polyhalits, Inaug. Diss. Berlin, 1901; also given in a paper by van 't Hoff, Zeit. anorg. Chem., 47, 244 (1905).

[c] Loc. cit.

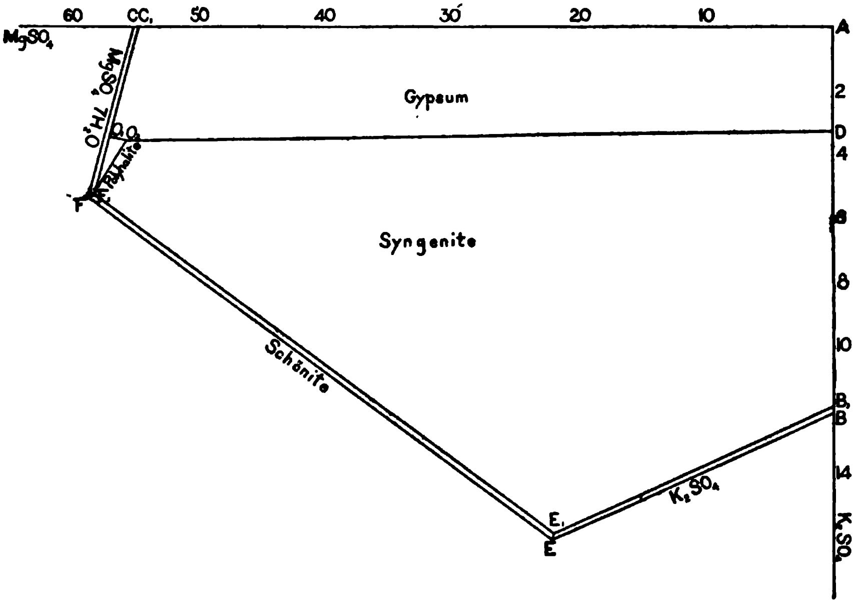

FIG. 5.—Diagram showing the conditions obtaining at 25° C. in the system composed of the sulphates of calcium, potassium, and magnesium.

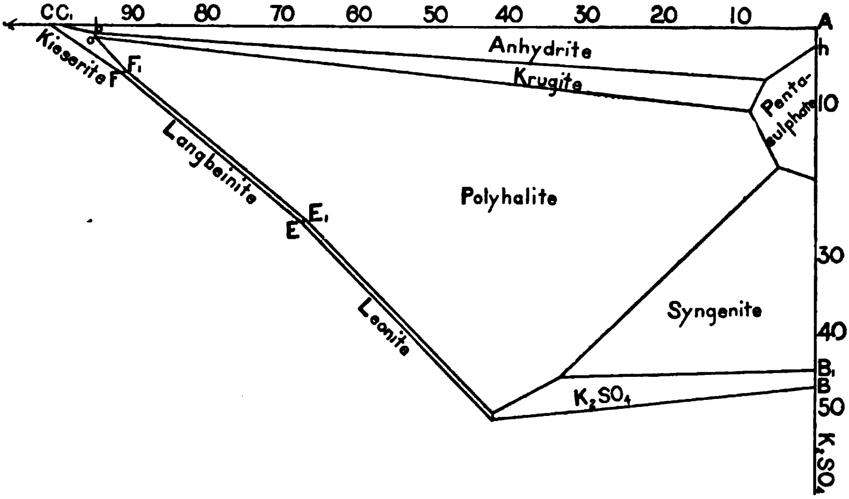

FIG. 6.—Diagram showing the conditions obtaining at 83° C. in the system composed of the sulphates of calcium, potassium, and magnesium.

not only have phases stable at 25° disappeared and new solid phases appeared, but also the limits of concentration, under which solids stable at both temperatures exist, have changed very greatly. Gypsum, which was the stable solid phase over a wide range of concentrations at 25°, can not exist at 83°; krugite, pentacalcium sulphate, and anhydrite, unstable in the presence of all solutions of the three original sulphates at 25°, are stable at 83°. Syngenite, which is stable with the larger number of the possible solutions at 25°, is stable in a comparatively small number of the possible solutions at 83°, and polyhalite, which can exist at 25° with solutions within narrow limits of concentration, at 83° is the stable solid with a majority of the possible solutions.

Table XVII.—*Concentration of solutions, stated in mols. of salt to 1,000 mols. water, at invariant points at 25° C.*

Point on plate.	Solids present in contact with the solution.	Concentration of the solution.		
		K_2SO_4.	$MgSO_4$.	$CaSO_4$.
A	Gypsum	0	0	0.35
B	K_2SO_4	12	0	0
C	$MgSO_4.7H_2O$	0	54.8	0
D	Gypsum, syngenite	3.3	0	.25
E	K_2SO_4, schönite	16	22	0
F	$MgSO_4.7H_2O$, schönite	5.3	58.3	0
B_1	K_2SO_4, syngenite	12	0	....
C_1	$MgSO_4.7H_2O$, gypsum	0	54.8	....
E_1 .. .	K_2SO_4, schönite, syngenite	16	22	....
F_1	$MgSO_4.7H_2O$, schönite, syngenite	5.3	58.3	....
O_1	Polyhalite, $MgSO_4.7H_2O$, gypsum	3.6	55.7	....
O_2	Polyhalite, syngenite, gypsum	3.5	56.7	....
O_3	Polyhalite, $MgSO_4.7H_2O$, syngenite	5.1	58.1	....

Table XVIII.—*Concentration of solutions, stated in mols. of salt to 1,000 mols. water at invariant points at 83°.*

Point on plate.	Solids present in contact with the solution.	Concentration of the solution.	
		K_2SO_4.	$MgSO_4$.
A	Anhydrite	0	0
B	K_2SO_4	45.5	0
C	Kieserite	0	100.5
D	K_2SO_4, leonite	51	42.5
E	Langbeinite, leonite	25.5	67
F	Langbeinite, kieserite	6	90.5
B	K_2SO_4, syngenite	45	0
C_1	Kieserite, anhydrite	0	100.5
D_1	K_2SO_4, leonite, polyhalite	51	42.5
E_1	Leonite, langbeinite, polyhalite	25.5	67
F_1	Langbeinite, kieserite, polyhalite	6	90.5
G	K_2SO_4, syngenite, polyhalite	46	33.5
b	Kieserite, anhydrite, krugite	1	94
h	Pentasulphate, anhydrite	2.5	0
n	Pentasulphate, anhydrite, krugite	7	6.5
o	Kieserite, polyhalite, krugite	(1)	(94)
p	Pentasulphate, polyhalite, krugite	11	8.5
q	Syngenite, pentasulphate, polyhalite	18.5	4.5
r	Syngenite, pentasulphate	20	0

The line AC_1 of figure 5 represents solutions which contain magnesium and calcium sulphates and which are saturated with gypsum. The composition of these solutions with respect to calcium sulphate has been determined in this laboratory.[a]

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[a] Cameron and Bell, Jour. Phys. Chem., 10, 210 (1906).

The line **CC_1** represents solutions which contain the same components as before, but which are saturated with magnesium sulphate ($MgSO_4.7H_2O$). At the point C_1, representing a "constant solution," the solids are gypsum and magnesium sulphate. The data for the concentration of the solution as found by Basch agrees well with the data determined in this laboratory.[a]

The line **AB** represents solutions which contain potassium sulphate and calcium sulphate. The part of the line **AD** represents solutions saturated with gypsum, and at **D** there is a complete change in the solid phase, a double sulphate of calcium and potassium (syngenite) appearing and gypsum disappearing. At **D** we have therefore solutions saturated with respect to both gypsum and syngenite, the length of the line **AD** representing the concentration of potassium sulphate in the solution at this point. The content of calcium sulphate in the solutions along **AB** have been determined by Cameron and Breazeale,[b] and the composition of the solution at the point **D**, a "constant" solution, as found by Basch agrees fairly well with the data of Cameron and Breazeale.

At points within the diagram there are solutions containing all three sulphates, the solid phase being that indicated on the diagram. There are five "constant solutions," at **O_1**, **O_2**, **O_3**, **F_1**, and **E_1**. At **O_2**, for instance, the solution is saturated with gypsum, syngenite, and polyhalite, the fields all meeting in that point. Similarly, at the points representing the other constant solutions the solid phases are those whose fields meet in that point.

The line **AC** represents solutions containing no potassium sulphate, and the line **AB** represents solutions containing no magnesium sulphate. Using this method of representation the solutions containing no calcium sulphate are represented by the line **CF**, along which $MgSO_4.7H_2O$ is the stable solid, the line **FE**, along which schönite is the stable solid, and the line **EB**, along which potassium sulphate is the stable solid.

General remarks on the effect of sulphates.

The results of all these investigations have been recalculated where it has been necessary to plot them on the same scale.

It will be observed from this diagram (fig. 7) that all the sulphates, with the exception of sulphuric acid, decrease the solubility of gypsum, as would be expected of compounds with a common ion. In the case of sulphuric acid solution containing 0.48 gram per liter the solubility of gypsum is the same as in pure water, and it seems probable that there may be a slight falling off in solubility for lower concentrations of sulphuric acid. At the higher concentrations in all cases the solubility increases, indicating that there is certainly some factor or factors other than the common ion influencing the solubility. It is suggested that at higher concentrations the sulphates of the type R_2SO_4 dissociated according to the scheme

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[a] Cameron and Bell, Jour. Phys. Chem., **10**, 210 (1906).

[b] Jour. Phys. Chem., 8, 334 (1904).

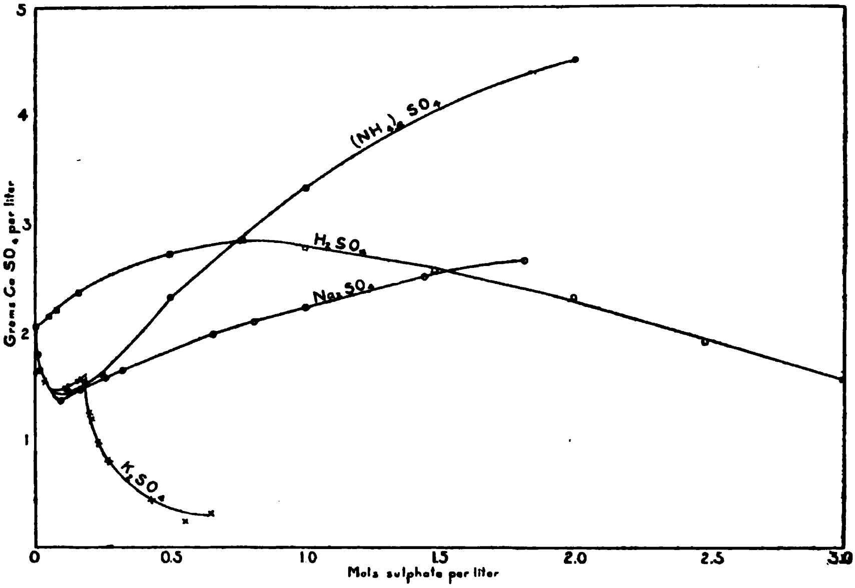

FIG. 7.—Solubility of calcium sulphates in various sulphate solutions at 25° C.

$$R_2SO \rightleftharpoons \overset{+}{R} + \overset{-}{RSO_4}$$

and as the ions are different from those of calcium sulphate, which can hardly dissociate according to any other scheme than

$$CaSO_4 \rightleftharpoons \overset{++}{Ca} + \overset{=}{SO_4}$$

then the solubility will tend to increase. However, in the case of magnesium sulphate, which dissociates similarly to calcium sulphate,

$$MgSO_4 \rightleftharpoons \overset{++}{Mg} + \overset{=}{SO_4}$$

there is certainly a common ion added, yet we have the same kind of an increasing solubility. It seems fair to suppose, therefore, that there is some other factor of which as yet we are completely ignorant. This solubility curve in the case of magnesium sulphate and of sulphuric acid shows a maximum point; in the case of sodium, potassium, and ammonium sulphate the curvature indicates an approach to a maximum point, but before it is reached the curve ends, for a new phase appears. It seems reasonable to suppose that for small amounts of the salt the solubility of gypsum is depressed by the addition of a common ion, but at greater concentrations some specific solvent action of the undissociated salt or of the ions themselves is experienced and the curve rises, or else the dissociation of the dissolved salts may be partial, thus giving no common ion. The assumption of any specific solvent action seems also to be rather doubtful, for at high concentrations the curves seem to pass through a maximum and decrease again. Another possible factor influencing the solubility of one salt in the solutions of another salt is the change in density of water consequent upon the addition of the salt. An appreciable change in the density of water can be brought about, at constant temperature, only by an enormous pressure, which would be so great as to materially alter the solubility of a second salt.

It is apparent that all the factors governing the solubility are not yet unknown, and no consistent formulation can be made with our present data.

SOLUBILITY OF CALCIUM SULPHATE IN SOLUTIONS OF CALCIUM SALTS.

Calcium hydroxide.

The mutual solubility of gypsum in lime solutions and of calcium hydroxide in gypsum solutions has quite recently been determined at 25° C. in this laboratory by Cameron and Bell with the following results:

TABLE XIX.—*Mutual solubility of gypsum and lime at 25° C.*

$CaSO_4$ per liter.	CaO per liter.	Solid phase.
Grams.	*Grams.*	
0	1.166	$Ca(OH)_2$.
.391	1.141	$Ca(OH)_2$.
.666	1.150	$Ca(OH)_2$.
.955	1.215	$Ca(OH)_2$.
1.214	1.212	$Ca(OH)_2$.
1.588	1.222	$Ca(OH)_2$, $CaSO_4.2H_2O$.
1.634	.939	$CaSO_4.2H_2O$.
1.722	.611	$CaSO_4.2H_2O$.
1.853	.349	$CaSO_4.2H_2O$.
1.918	.176	$CaSO_4.2H_2O$.
2.032	.062	$CaSO_4.2H_2O$.
2.126	0	$CaSO_4.2H_2O$.

It will be seen from these results that with increasing lime content in the solution the solubility of gypsum is steadily depressed. With increasing amounts of gypsum in the solution the solubility of lime seems to be nearly the same as in pure water.

Calcium chloride.

Tilden and Shenstone[a] have determined at different temperatures the solubility of calcium sulphate in solutions containing 15 parts of calcium chloride to 100 parts of water. They find a maximum solubility in the neighborhood of 95° C. The data are as follows, the determinations at high temperatures being made, of course, in sealed tubes:

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[a] Proc. Roy. Soc., 38, 331 (1885).

TABLE XX.—*Solubility of calcium sulphate in solutions of calcium chloride.*

Temperature.	Parts $CaCl_2$ per 100 parts H_2O.	Quantity $CaSO_4$ in 100 c. c. solution.	Temperature.	Parts $CaCl_2$ per 100 parts H_2O.	Quantity $CaSO_4$ in 100 c. c. solution.
° *C.*		*Gram.*	° *C.*		*Gram.*
15	15.00	0.063	94	15.16	0.110
21	14.70	.086	138	14.70	.070
39	15.00	.091	170	14.82	.031
72	14.90	.100	195	14.70	.022

These results show that there is a break in the curve at about 100°, which has been found by van 't Hoff and Armstrong[a] to be the point at which there is a change of solid phase.

Lunge[b] has determined the solubility of gypsum in different calcium chloride solutions at 23–25° C. and at 101–103° C., with the following results:

TABLE XXI.—*Solubility of calcium sulphate in solutions of calcium chloride.*

Temperature.	Per cent $CaCl_2$ solution.	Quantity $CaSO_4$ in 100 c. c. of solution.	Temperature.	Per cent $CaCl_2$ solution.	Quantity $CaSO_4$ in 100 c. c. of solution.
° *C.*		*Gram.*	° *C.*		*Gram.*
23	3.54	0.1225	25.0	16.91	0.0702
24	6.94	.0963	101.0	8.54	.1370
25	10.35	.0886	102.5	10.36	.1426
25	15.90	.0734	103.5	16.91	.1301

The solubility at 25° has been given by Cameron and Seidell[c] as follows:

TABLE XXII.—*Solubility of calcium sulphate in solutions of calcium chloride at 25° C.*

Quantity $CaSO_4$ per liter.	Quantity $CaCl_2$ per liter.	Quantity $CaSO_4$ per liter.	Quantity $CaCl_2$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*
2.056	0.000	1.016	51.530
1.244	7.489	.841	97.023
1.181	11.959	.465	192.705
1.096	25.770	.203	280.303
1.080	32.015	.032	367.850

[a] Sitzungsber. Akad. Wiss. Berlin, 1900, 559.

[b] Jour. Soc. Chem. Ind., 4, 31 (1885).

[c] Jour. Phys. Chem. 5, 643 (1901).

The solubility of gypsum in calcium chloride solutions as given by Orloff[a] is as follows:

TABLE XXIII.—*Solubility of calcium sulphate in solutions of calcium chloride.*

Proportion $CaCl_2$ in solution.	Quantity of $CaSO_4$ in 100 grams of solution.	Proportion $CaCl_2$ in solution.	Quantity of $CaSO_4$ in 100 grams of solution.
Per cent.	*Grams.*	*Per cent.*	*Gram.*
0.5	1.4040	15.0	0.7614
1.0	1.1300	20.0	.5548
2.0	1.125	30.0	.1868
5.0	1.0362	40.0	.1278
10.0	.8513		

The solubility of the calcium sulphate decreases very rapidly as the concentration with respect to calcium chloride increases, until a concentration of about 20 grams per liter of this latter salt is reached. From this point the solubility of the calcium decreases more slowly, but steadily, and by extrapolation on the curve it would seem that a solution containing 375 grams per liter of calcium chloride would dissolve practically no calcium sulphate.

Just why there should be so marked a change in the solubility of the calcium sulphate in solution concentrations of about 2 per cent calcium chloride does not admit of explanation as yet. It is possible that at concentrations above this the calcium chloride may partially dissociate in such a way as to form complex ions containing both calcium and chlorine,[b] and thus diminish the proportional effect of calcium as ions in the solutions, forcing back the dissociation of the calcium chloride and consequently the retarding effect upon the solubility of the calcium sulphate. It seems probable, however, that the density of the solvent itself may have an important rôle in this connection.

The effect of calcium chloride in solution upon the transition temperature of gypsum has been determined by van 't Hoff and Armstrong by consideration of the vapor pressures of the solid gypsum and of that of the solution in question. For a saturated solution this temperature is about 17°; for a 15 per cent solution it is slightly over 100° C. This temperature agrees with the results of Tilden and Shenstone[c] on the solubility of calcium sulphate in solutions of calcium sulphate.

Calcium nitrate.

The effect of calcium nitrate in solution upon the solubility of calcium sulphate at 25° has been studied by Seidell and Smith.[d] The results of this work are given in Table XXIV.

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[a] Jour. Russ. Phys. Chem. Soc., **34**, 949 (1902).

[b] Noyes. Phys. Rev., **12**, 15 (1901); Jour. Am. Chem. Soc., **23**, 37 (1901); Zeit. phys. Chem., **36**, 61 (1901).

[c] Proc. Roy. Soc., **38**, 331 (1885).

[d] Jour. Phys. Chem., **8**, 493 (1904).

TABLE XXIV.—*Solubility of calcium sulphate in solutions of calcium nitrate at 25° C.*

Weight of 1,000 c. c. of solution.	Quantity $Ca(NO_3)_2$ per liter of solution.	Quantity $CaSO_4$ per liter of solution.	Weight of 1,000 c. c. of solution.	Quantity $Ca(NO_3)_2$ per liter of solution.	Quantity $CaSO_4$ per liter of solution.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
998.1	0	2.084	1,203.5	300	0.759
1,013.8	25	1.238	1,265.6	400	.569
1,031.7	50	1.196	1,328.1	500	.403
1,067.3	100	1.134	1,352	544	.346
1,136.9	200	.929			

General remarks on the effect of calcium salts.

The effect of calcium salts on the solubility of calcium sulphate is to depress the solubility more and more as the amount of the calcium salt increases. This result is in no way remarkable, as it follows the rule that the addition of a salt with a common ion depresses the solubility.

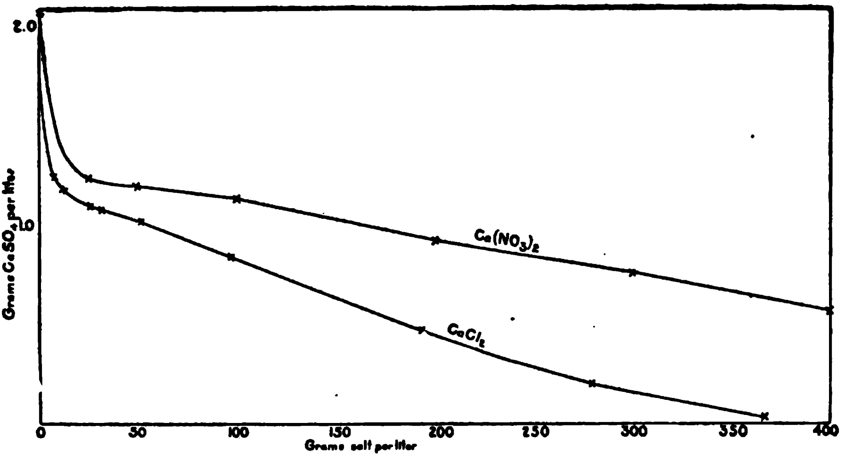

FIG. 8.—Solubility of calcium sulphate in solutions of calcium salts at 25° C.

SOLUBILITY OF CALCIUM SULPHATE IN SOLUTIONS OF ELECTROLYTES NOT CONTAINING A COMMON ION.

Hydrochloric acid.

The solubility of calcium sulphate in hydrochloric acid solutions has been studied by Banthisch,[a] working under Oswald's direction, and the results of this investigation have been recalculated so as to give grams of each solute per liter of solution.

TABLE XXV.—*Solubility of calcium sulphate in hydrochloric acid solutions at 25° C.*

Quantity HCl per liter of solution.	Quantity $CaSO_4$ per liter of solution.
Grams.	*Grams.*
0	(2.062)
3.618	4.357
18.090	9.935
36.180	13.565
72.360	17.275

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[a] Jour. prakt. Chem., 137, 52 (1884).

Lunge's results[a] on this subject can not be calculated on the same basis, but, assuming the density of the solution to be the same as water (and they do not vary much from this figure), it will be seen from Table XXV that they agree well with Banthisch's results at 25°.

TABLE XXVI.—*Solubility of calcium sulphate in hydrochloric acid solutions at 25° C.*

Temperature.	Proportion of HCl.	Quantity $CaSO_4$ per liter of solution.	Temperature.	Proportion of HCl.	Quantity $CaSO_4$ per liter of solution.
° *C.*	*Per cent.*	*Grams.*	° *C.*	*Per cent.*	*Grams.*
25	0.77	6.405	25	6.12	16.539
25	1.56	8.821	101	.77	11.209
25	3.06	12.639	102	3.06	31.780
25	4.70	15.342	103	6.12	46.902

Ammonium chloride.

The solubility of gypsum has been found by Vogel[b] to be greater in ammonium chloride than in pure water.

Fassbender[c] gives the ratio of gypsum to ammonium chloride as 1 to 92 in a saturated solution at 15°. The following results have been determined by Droeze:[d]

TABLE XXVII.—*Solubility of calcium sulphate in ammonium chloride solutions.*

Temperature.	Concentration of NH_4Cl solution.	Quantity $CaSO_4$ per liter of solution.
° *C.*		*Grams.*
13.5......	Saturated	10.772
13.5......	½ saturated	10.320
13.5......	¼ saturated	4.988
Boiling..	¼ saturated	5.461

Tilden and Shenstone[e] have studied the effect of temperature on the solubility of $CaSO_4$ in a solution of ammonium chloride containing 25 parts of the salt to 100 parts of water. The results in Table XXVIII show a maximum solubility in the neighborhood of 60°.

TABLE XXVIII.—*Solubility of calcium sulphate in 20 per cent solutions of ammonium chloride.*

Temperature.	Quantity $CaSO_4$ in 100 grams water.	Temperature.	Quantity $CaSO_4$ in 100 grams water.
° *C.*	*Grams.*	° *C.*	*Grams.*
8	1.030	60	1.133
9	1.023	80	1.026
25	1.096	120	1.000
39	1.126		

[a] Jour. Soc. Chem. Ind., 4, 31 (1885).

[b] Repert. Phar. (3), 5, 342 (1850).

[c] Ber., 9, 1358 (1876).

[d] Ber., 10, 330 (1877).

[e] Proc. Roy. Soc., 38, 331 (1885).

Table XXIX gives Cohn's results[a] recalculated to give the amount of each salt in 100 grams of water.

TABLE XXIX.—*Solubility of calcium sulphate in ammonium chloride solutions at 20° C.*

Quantity of NH_4Cl in 100 parts solution.	Quantity $CaSO_4$ in 100 parts solution.	Quantity of NH_4Cl in 100 parts solution.	Quantity $CaSO_4$ in 100 parts solution.
Grams.	*Grams.*	*Grams.*	*Grams.*
3.242	0.56391	16.105	0.83311
6.617	.71065	18.730	.81276
10.488	.79769	21.360	.78219
12.036	.82522	25.327	.74354

These results show either that the solubility has become practically constant at higher concentrations or that it has reached a maximum point and tends to fall off again.

The results obtained by Ditte[b] show no such maximum, when recalculated to give grams of each salt per liter of solution.

TABLE XXX.—*Solubility of calcium sulphate in solutions of ammonium chloride.*

Quantity NH_4Cl per liter of solution.	Quantity $CaSO_4$ per liter of solution.	Quantity NH_4Cl per liter of solution.	Quantity $CaSO_4$ per liter of solution.
Grams.	*Grams.*	*Grams.*	*Grams.*
0	2.43	120	9.13
20	5.38	200	9.71
40	6.94	280	10.25
60	8.01	333	10.69
80	8.91		

The data published by Cameron and Brown,[c] however, show a distinct maximum point at 25°.

TABLE XXXI.—*Solubility of calcium sulphate in ammonium chloride solution at 25°.*

Quantity NH_4Cl per liter of solution.	Quantity $CaSO_4$ per liter of solution.	Quantity NH_4Cl per liter of solution.	Quantity $CaSO_4$ per liter of solution.
Grams.	*Grams.*	*Grams.*	*Grams.*
10.8	3.90	198.6	10.85
24.4	5.38	210	10.88
46.7	7.07	275	10.60
94.5	8.80	325	9.40
149.7	10.30	[a]375.3	7.38

[a] Saturated.

Sodium Chloride.

The earliest experimenter on the solubility of gypsum in common salt solutions was Droeze[d]. His results, given in the following table, can not be computed for comparison with any of the latter work.

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[a] Jour. prakt. Chem., **143**, 43 (1887).

[b] Compt. rend., **126**, 694 (1898).

[c] Jour. Phys. Chem., **9**, 210 (1905).

[d] Ber., **10**, 330 (1877).

TABLE XXXII.—*Solubility of calcium sulphate in solutions of sodium chloride.*

Temperature.	Concentration of NaCl solution.	Quantity gypsum in 100 c. c.
°*C.*		*Gram.*
8.5	Saturated	0.6785
13.5	.....do	.6665
13.5	½ saturated	.6708
13.5	⅛ saturated	.4085

Tilden and Shenstone[a] have studied the effect of temperature upon the solubility of gypsum in salt solutions containing 20 parts of salt to 100 parts of water. Their results are given in Table XXXIII.

TABLE XXXIII.—*Solubility of calcium sulphate in solutions of sodium chloride.*

Temperature.	Parts NaCl to 100 parts H_2O.	Part $CaSO_4$ to 100 parts H_2O.	Temperature.	Parts NaCl to 100 parts H_2O.	Part $CaSO_4$ to 100 parts H_2O.
° *C.*			° *C.*		
20	19.90	0.823	130	19.92	0.392
44	19.93	.830	165	20.04	.250
67	19.95	.832	169	20.05	.244
85	19.90	.823	179	20.10	.229
101	20.08	.682	225	21.00	.178

It will be seen from the table that the solubility drops abruptly at about 100° C. There is a change of solid phase in this neighborhood, $CaSO_4.2H_2O$ changing into $2CaSO_4H_2O$ at 95°, as has been shown by van 't Hoff and Armstrong.[b] Tilden and Shenstone have also determined the solubility of calcium sulphate in different salt solutions at 20° C., with the results shown in Table XXXIV.

TABLE XXXIV.—*Solubility of calcium sulphate in solutions of sodium chloride at 20° C.*

Parts NaCl to 100 parts water.	Part $CaSO_4$ to 100 parts water.	Parts NaCl to 100 parts water.	Part $CaSO_4$ to 100 parts water.
0.000	0.225	10.00	0.738
.52	.301	20.00	.823
2.03	.441	24.40	.820
5.02	.615	35.10	.734
5.05	.634	35.86	.709

These figures show that there is a maximum solubility at 20° in a solution of salt containing 20 parts of salt to 100 parts of water.

The results of Lunge[c] indicate that the solubility of gypsum increases with the amount of common salt in the solution, and also that for the same solution the solubility is lower at 100° than at 20° C.

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[a] Proc. Roy. Soc., **38**, 331 (1885).

[b] Sitzungsber. Akad. Wiss. Berlin, 1900, 559.

[c] Jour. Soc. Chem. Ind., **4**, 31 (1885).

TABLE XXXV.—*Solubility of calcium sulphate in sodium chloride solutions.*

Temperature.	NaCl in solution.	$CaSO_4$ per 100 c. c. of solution.	Temperature.	NaCl in solution.	$CaSO_4$ per 100 c. c. of solution.
° *C.*	*Per cent.*	*Gram.*	° *C.*	*Per cent.*	*Gram.*
21.5	3.53	0.5715	17.0	17.46	0.7369
19.5	7.35	.6429	101.0	3.53	.4891
21.0	11.12	.7215	102.5	14.18	.6248
18.0	14.18	.7340	103.0	17.46	.6299

Ditte[a] finds that at the temperature at which he worked (about room temperature) there is no separation of a double sulphate of calcium and sodium. Cameron[b] has determined the solubility of calcium sulphate in different sodium chloride solutions at several temperatures. In Tables XXXVI and XXXVII are the results of this work:

TABLE XXXVI.—*Solubility of calcium sulphate in sodium chloride solutions at different temperatures.*

[Grams per liter.]

At 15° C.		At 23° C.		At 26° C.		
NaCl.	$CaSO_4$.	NaCl.	$CaSO_4$.	NaCl.	$CaSO_4$.	Density of solution.
0.6	2.3	0.99	2.37	0	2.121	0.9998
1.1	2.5	4.95	3.02	91.154	6.656	1.0644
5.1	3.1	10.40	3.54	143.989	7.179	1.0981
10.6	3.7	30.19	4.97	148.343	7.164	1.1012
31.1	4.8	49.17	5.94	176.502	7.119	1.1196
51.4	5.6	75.58	6.74	228.756	6.791	1.1488
139.9	7.4	129.50	7.50	264.173	6.498	1.1707
		197.20	7.25	320.491	5.715	1.2034
		229.70	7.03			
		306.40	5.68			
		[a]315.55	5.37			

[a] Saturated.

TABLE XXXVII.—*Solubility of calcium sulphate in sodium chloride solutions at different temperatures.*

[Grams per liter.]

At 30° C.		At 52° C.		At 70° C.		At 82° C.	
NaCl.	$CaSO_4$	NaCl.	$CaSO_4$.	NaCl.	$CaSO_4$.	NaCl.	$CaSO_4$.
0.5	2.5	0.5	2.3	0.5	2.2	0	2.07
10.3	3.6	1.1	2.4	10.0	3.4	1.0	2.18
30.3	5.0	5.0	2.9	29.6	4.9	5.0	2.65
47.3	6.1	10.1	3.5	48.8	5.8	10.1	3.30
73.4	6.9	29.6	5.0	132.7	7.4	29.5	4.68
126.9	7.3	48.3	5.8	195.0	7.6	48.8	5.54
192.4	7.7	75.7	6.6			74.9	6.23
		131.6	7.1			128.7	7.00
		195.6	7.4			195.1	7.51

It is to be seen from these observations, at least at the lower temperatures, 23° and 26°, that the result of Tilden and Shenstone is confirmed, namely, that there is a maximum in the solubility curve. This does not seem to exist for temperatures above 30°.

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[a] Compt. rend., **126**, 694 (1898).

[b] Jour. Phys. Chem., **5**, 556 (1901).

The following results by Orloff[a] indicate that there is a maximum in the solubility curve.

TABLE XXXVIII.—*Solubility of calcium sulphate in solutions of sodium chloride.*

NaCl in solution.	Quantity of $CaSO_4$ in 100 grams solution.	NaCl in solution.	Quantity of $CaSO_4$ in 100 grams solution.
Per cent.	*Grams.*	*Per cent.*	*Grams.*
0.5	2.8885	10.0	6.5385
1.0	3.3652	15.0	6.4222
2.0	4.2602	20.0	5.8991
5.0	5.5737		

The results of Cloez[b] do not agree well with the above results by Orloff and by Cameron, for no maximum solubility is found. The results at 14° C. are as follows:

TABLE XXXIX.—*Solubility of calcium sulphate in sodium chloride solutions at 14° C.*

Concentration of NaCl in 100 c. c. of solution.	Quantity of $CaSO_4$ in 100 c. c. of solution.	Concentration of NaCl in 100 c. c. of solution.	Quantity of $CaSO_4$ in 100 c. c. of solution.
Grams.	*Grams.*	*Grams.*	*Grams.*
2.44	0.635	14.22	0.193
4.77	.826	23.12	1.275
9.50	1.056	31.30	1.583

The solubility of gypsum in common salt solutions has been determined by d'Anselme[c] who found that brines from salt wells always contain more gypsum than the same amount of pure water would dissolve. This content of gypsum always causes trouble in the preparation of soda from the salt, for in the ammonia process the mixed gases carbon dioxide and ammonia always precipitate the lime from solution. These solubility determinations are in very good accord with those of Cameron.

TABLE XL.—*Solubility of calcium sulphate in sodium chloride solutions at different temperatures.*

[Grams per liter.]

NaCl.	$CaSO_4$ at 14° C.	$CaSO_4$ at 20° C.	NaCl.	$CaSO_4$ at 14° C.	$CaSO_4$ at 20° C.	NaCl.	$CaSO_4$ at 14° C.	$CaSO_4$ at 20° C.
0	1.70	2.10	58.50	5.72	6.00	160.8	7.00	7.05
2.925	2.32	2.70	87.75	6.58	6.85	175.6	6.80	6.80
5.850	2.79	3.15	102.3	6.90	7.15	204.7	6.30	6.30
11.70	3.41	3.75	117.0	7.10	7.30	234.0	5.90	5.90
14.62	3.68	4.00	131.6	7.20	7.30	263.2	5.50	5.52
29.25	4.40	4.70	146.2	7.10	7.13	292.6	5.30	5.30

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[a] Jour. Russ. Phys. Chem. Soc., **34**, 949 (1902).

[b] Bul. Soc. Chim. (3), **29**, 167 (1903).

[c] Bul. Soc. Chim. (3), **29**, 372 (1903).

The effect of sodium chloride in solution upon the transition temperature of gypsum has been studied by van 't Hoff and Armstrong[a] by the method of vapor tensions. The vapor tension curve for gypsum crosses the vapor tension curve of the solution saturated with both salts at the temperature 77° C., and consequently this is the transition temperature of gypsum in the presence of a solution saturated with common salt. For a 17 per cent salt solution this temperature was found to be at 95°, a result which is in accord with the experimental results of Tilden and Shenstone[b] on the solubility of calcium sulphate in a 17 per cent salt solution. The solubility curve abruptly changes its direction at about this temperature, owing to the change in the stable solid phase. For a 3½ per cent solution the transition temperature was found to be 105° C.

Potassium chloride.

Comparatively little work has been done on the solubility of calcium sulphate in potassium chloride solution. Fassbender[c] gives the result of one experiment; at 8° C. 1 part of gypsum dissolves in 162 parts of saturated potassium chloride solution. Droeze[d] confirms the result and finds that 1 part of gypsum dissolves in 295 parts of a one-fifth saturated KCl solution. The solubility of gypsum in different KCl solutions at 21° has been studied by Ditte.[e] His results indicate that at high concentrations the double sulphate crystallizes out, leaving less of the SO_4 group in solution than corresponds to the calcium in solution. The results have been recalculated, and are given in Table XLI.

TABLE XLI.—*Solubility of calcium sulphate in potassium chloride solutions at 21° C.*

Quantity KCl per liter.	Quantity $CaSO_4$ per liter.	Quantity KCl per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*
0	2.05	24	3.75
4	2.32	40	4.73
12	3.06	60	5.28
20	3.61	80	5.81

For greater concentrations the solid phase was not gypsum, but the double sulphate.

Potassium bromide and potassium iodide.

Ditte[f] says the results for these two salts are similar to those for the chloride, i. e., the solubility increases with increasing salt content until the double sulphate separates.

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[a] Sitzungsber. Akad. Wiss. Berlin, 1900, 559.

[b] Proc. Roy. Soc., **38**, 331 (1885).

[c] Ber., **9**, 1358 (1876).

[d] Ber., **10**, 330 (1877).

[e] Compt. rend., **126**, 694 (1898).

[f] Compt. rend., **126**, 694 (1898); see also Struve, Zeit. Chem., **5**, 324 (1869).

Magnesium chloride.

One result on the solubility of gypsum is given by Droeze,[a] namely, 1 part of gypsum dissolves in 146 parts of a one-ninth saturated $MgCl_2$ solution at 13.5° C. Tilden and Shenstone[b] have given determinations at three temperatures (see Table XLII) on which no conclusion can be based.

TABLE XLII.—*Solubility of calcium sulphate in solutions of magnesium chloride.*

Temperature.	Quantity of salt in 100 parts water.	
	$MgCl_2$.	$CaSO_4$.
	Grams.	*Grams.*
9	19.8	0.771
39	11.1	2.774
80	9.99	1.038

Cameron and Seidell[c] have studied the solubility of calcium sulphate in magnesium chloride solutions at 26°. The results of their work are given in Table XLIII.

TABLE XLIII.—*Solubility of calcium sulphate in solutions of magnesium chloride at 26° C.*

[Grams per liter.]

Water.	$MgCl_2$.	$CaSO_4$.	Water.	$MgCl_2$.	$CaSO_4$.
997.924	0	2.082	972.218	121.381	8.622
996.520	8.501	4.258	949.950	206 985	6.567
994.489	19.175	5.692	908.678	336.986	2.774
989.143	46.640	7.588	878.588	441.128	1.385

It is evident from the table that the solubility of $CaSO_4$ passes through a maximum. The content of $CaSO_4$ in 100 grams of a 10 per cent solution of $MgCl_2$ is given by Orloff[d] as 8.966 grams. The solution saturated with both salts at 25° contains[e] 476.9 grams $MgCl_2$ per liter and 1.09 grams $CaSO_4$ per liter.

The transition temperature for gypsum in the presence of a solution saturated with magnesium chloride has been determined by van 't Hoff and Armstrong[f] to be about 11° C.

Nitric acid.

The measurements of Banthisch[g] on the solubility of gypsum in nitric acid solutions shows that the amount of gypsum in solution increases with increasing concentration of the acid. These results are as follows:

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[a] Ber., **10**, 340 (1877).

[b] Proc. Roy. Soc., **38**, 331 (1885).

[c] Jour. Phys. Chem., **5**, 643 (1901).

[d] Jour. Russ. Phys. Chem. Soc., **34**, 949 (1902).

[e] Cameron and Brown, Jour. Phys. Chem., **9**, 210 (1905).

[f] Sitzungsber. Akad. Wiss. Berlin, 1900, 559.

[g] Jour. prakt. Chem., **137**, 52 (1884).

TABLE XLIV.—*Solubility of calcium sulphate in solutions of nitric acid at 25° C.*

Quantity HNO_3 per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*
6.257	4.397
31.285	10.435
62.57	15.147
225.14	20.607

Ammonium nitrate.

Droeze[a] has studied the solubility of gypsum in ammonium nitrate solutions and has found that at 13.5° the solubility passes through a maximum point, as the following table shows. The results can not be computed for comparison with more modern data.

TABLE XLV.—*Solubility of calcium sulphate in ammonium nitrate solutions at different temperatures.*

Temperature.	Concentration of NH_4NO_3 solution.	Quantity of gypsum in 100 c.c.
° C.		*Grams.*
8–9	Saturated..........	0.312
13.5	$\frac{2}{3}$ saturated........	1.843
13.5	$\frac{2}{27}$ saturated.......	.967

The results of Cohn[b] have been recalculated to give the percentage amount of each salt in the solution.

TABLE XLVI.—*Solubility of calcium sulphate in ammonium nitrate solutions at different temperatures.*

At 20° C.		At 27.5° C.	
Quantity NH_4NO_3 per 100 grams solution.	Quantity $CaSO_4$ per 100 grams solution.	Quantity NH_4NO_3 per 100 grams solution.	Quantity $CaSO_4$ per 100 grams solution.
Grams.	*Grams.*	*Grams.*	*Grams.*
4.667	0.6074	27.544	1.0280
8.490	.7720	35.932	1.0190
14.346	.9006	43.616	.9680
18.883	.9701	51.148	.8845
23.229	1.0220	58.303	.7965
28.211	1.0480	63.814	.7227
30.905	1.0467		
36.089	1.0308		

From the first two columns of the above table it will be observed that the solubility reaches a maximum at about 29 per cent NH_4NO_3 at 20° C. The results in the second two columns of this table describe solutions quite concentrated with ammonium nitrate, when the solubility has apparently passed through the maximum.

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[a] Ber., **10**, 330 (1877).

[b] Jour. prakt. Chem., **143**, 43 (1887).

In Table XLVII are given the results obtained by Cameron and Brown[a] with solutions of ammonium nitrate.

TABLE XLVII.—*Solubility of calcium sulphate in solutions of ammonium nitrate at 25° C.*

Quantity NH_4NO_3 per liter.	Quantity $CaSO_4$ per liter.	Quantity NH_4NO_3 per liter.	Quantity $CaSO_4$ per liter.	Quantity NH_4NO_3 per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
10	3.18	200	9.85	1,000	11.81
25	3.93	300	10.80	1,200	11.10
55	5.80	400	11.40	1,400	10.02
100	7.65	450	12.02	Saturated.	7.55
150	8.88	750	12.20		

It will be observed that the solubility of calcium sulphate in ammonium nitrate solutions increases at first with increasing concentration of the more soluble salt, the maximum solubility being approximately 12.2 grams in a solution containing 750 grams of ammonium nitrate per liter. From this point, with increasing concentration of ammonium nitrate, the solubility of calcium sulphate decreases until both salts exist as solid phases, in which case the amount dissolved is 7.55 grams calcium sulphate per liter.

Potassium nitrate.

The solubility of gypsum, according to Vogel,[b] is less in potassium nitrate solutions than in pure water. The results of Fassbender[c] give the solubility of gypsum in saturated solutions of potassium nitrate at two temperatures. At 15.5° there is one part gypsum in 82 c. c. saturated KNO_3 solution, and at 20° there is one part gypsum in 69 c. c. of the saturated solution. Droeze[d] confirms both these results and adds one more. At 13.5° there is one part gypsum in 94 c. c. saturated solution of KNO_3. Seidell and Smith[e] have determined the solubility in different potassium nitrate solutions at 25°. The results are given in the following table:

TABLE XLVIII.—*Solubility of calcium sulphate in solutions of potassium nitrate at 25° C.*

Weight of 1,000 c. c. of solution.	Quantity KNO_3 per liter.	Quantity $CaSO_4$ per liter.	Weight of 1,000 c. c. of solution.	Quantity KNO_3 per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
998.1	0.0	2.084	1,092.4	150.0	7.907
1,008.1	12.5	3.284	1,122.4	200.0	8.688
1,015.4	25.0	4.080	1,153.9	260.0	[f] 6.278 [g] 12.112
1,032.1	50.0	5.255			
1,062.5	100.0	6.855			

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[a] Jour. Phys. Chem., **9**, 210 (1905).

[b] Repert. Phar. (3), **5**, 342 (1850).

[c] Ber., **9**, 1358 (1876).

[d] Ber., **10**, 330 (1877).

[e] Jour. Phys. Chem., **8**, 493 (1904).

[f] Calculated from SO_4 determination.

[g] Calculated from Ca determination.

Sodium nitrate.

The solubility of gypsum in sodium nitrate solutions as determined by Droeze[a] is as follows: 92 c. c. of a sodium nitrate solution saturated at 8.5° will dissolve 1 gram gypsum.

A more complete study has been made by Seidell and Smith,[b] whose results are given in Table XLIX.

TABLE XLIX.—*Solubility of calcium sulphate in solutions of sodium nitrate at 25° C.*

Weight of 1,000 c. c. of solution.	Quantity $NaNO_3$ per liter.	Quantity $CaSO_4$ per liter.	Weight of 1,000 c. c. of solution.	Quantity $NaNO_3$ per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
998.1	0	2.084	1,133.6	200	8.790
1,016.3	25	4.252	1,191.6	300	9.282
1,034.0	50	5.500	1,363.9	600	7.886
1,068.4	100	7.100	1,390.4	655	7.238

From this table it will be observed that the solubility of gypsum passes through a maximum where 300 grams of sodium nitrate are dissolved in a liter. Cameron and Brown[c] have determined the concentration of the solution in equilibrium with both salts at 25°. This solution contains 668.4 grams $NaNO_3$ per liter and 7.16 grams $CaSO_4$ per liter.

Magnesium nitrate.

The solubility of gypsum in magnesium nitrate solutions has been determined mainly by Seidell and Smith,[d] and the results of their work are tabulated in Table L.

TABLE L.—*Solubility of calcium sulphate in solutions of magnesium nitrate at 25° C.*

Weight of 1,000 c. c. of solution.	Quantity $Mg(NO_3)_2$ per liter.	Quantity $CaSO_4$ per liter.	Weight of 1,000 c. c. of solution.	Quantity $Mg(NO_3)_2$ per liter.	Quantity $CaSO_4$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
998.1	0	2.084	1,149.8	200	13.340
1,020.5	25	5.772	1,219.0	300	14.000
1,039.8	50	7.884	1,282.1	400	14.683
1,078.6	100	9.920	1,355.3	514	15.040

The solution saturated with both salts at 25° has been found by Cameron and Brown[c] to contain 615.1 grams magnesium nitrate per liter and 15.26 grams $CaSO_4$ per liter.

Monochloracetic acid and formic acid.

Two determinations have been made by Banthisch[e] on the effect of monochloracetic acid on the solubility of gypsum. Solutions containing 46.87 and 93.74 grams monochloracetic acid per liter dissolve 2.147 and 2.472 grams, respectively, of calcium sulphate per liter at 25° C.

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[a] Ber., 10, 330 (1877).

[b] Jour. Phys. Chem., 8, 493 (1904).

[c] Jour. Phys. Chem., 9, 210 (1905).

[d] Jour. Phys. Chem., 8, 493 (1904).

[e] Jour. prakt. Chem., 137, 52 (1884).

This author has also found that a solution of formic acid containing 45.66 grams of acid per liter would dissolve 2.37 grams $CaSO_4$ per liter.

Phosphoric acid.

The solubility of gypsum in phosphoric acid solutions at 25° has been investigated recently in this laboratory by W. C. Taber. Solutions of phosphoric acid, to which solid gypsum have been added, have been analyzed for phosphoric acid, for lime, and for sulphuric acid. Equivalent amounts of lime and sulphuric acid have been found, indicating that there is no reaction between phosphoric acid and gypsum to produce a phosphate of calcium. The results of these experiments are as follows:

TABLE LI.—*Solubility of gypsum in phosphoric acid solutions at 25° C.*

Grams P_2O_5 per liter.	Grams $CaSO_4$ per liter.	Density of solutions $\frac{25°}{25°}$.	Grams P_2O_5 per liter.	Grams $CaSO_4$ per liter.	Density of solutions $\frac{25°}{25°}$.
0.0	2.126	....	145.1	7.920	1.106
5	3.143	1.002	205	8.383	1.145
10.5	3.734	1.007	311.5	7.965	1.221
21.4	4.456	1.016	395.8	6.848	1.280
46.3	5.760	1.035	494.6	5.572	1.344
105.3	7.318	1.075			

The table indicates that increasing amounts of phosphoric acid increase the solubility of gypsum at first, and above about 200 grams phosphoric anhydride per liter the solubility decreases. This is similar to the other electrolytes which have not an ion in common with gypsum.

Tartrate solutions.

Magnanini's experiments[a] show that the solubility of gypsum is about 4.5 per cent greater in N/200 aqueous solution of cream of tartar at 20° C. than in water. If this solution of cream of tartar contains also 5 per cent of tartaric acid the solubility exceeds that in pure water by about 15 per cent. In 10 per cent aqueous alcohol the solubility of gypsum is only about 40 per cent of that in water and this solubility is still further depressed by the addition of cream of tartar to N/400. If, however, tartaric acid be now added to 5 per cent and the solution saturated at 20° with carbon dioxide the solubility is increased.

Sodium thiosulphate.

The solubility of gypsum in sodium thiosulphate solutions has been found by Diehl[b] and Fuld[c] to be much greater than in water, and the former attributes this increased solubility to the formation of a double thiosulphate of calcium and sodium.

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[a] Gazz. chim. ital. **31 ii**, 542 (1901).

[b] Jour. prakt. Chem., **79**, 430 (1860).

[c] Jour. Chem. Soc., **16**, 28 (1863).

General remarks on the solubility of calcium sulphate in solutions of electrolytes which yield no common ion.

At very low concentrations, assuming that the salts are completely dissociated, the solubility of gypsum in the solution is influenced by the ions into which the salt is dissociated. The effect of compounds in solution with no common ion is to increase the solubility of gypsum, at least at the lower concentrations. This increase in solubility has been qualitatively found by Terreil[a] in the case of ammonium salts. In the case of a very dilute solution of sodium chloride, for example, the increase in concentration may be ascribed to the combined effects of the two ions. Now, let us consider also a solution of potassium chloride of the same molecular concentration at the same temperature. The concentration of the chlorine ions is the same in the two solutions, which, barring slight differences in density, differ only in one respect, namely, the nature of the positive ion. The difference in the solubility of gypsum in the two solutions must be attributed to the different effects of the two positive ions. Taking dilute solutions of chlorides of equal content of chlorine, i. e., equivalent weights, we may compare the effect of the various positive ions. The solubility of gypsum has been plotted in the foregoing figure (fig. 9), the ordinates being the number of equivalents of the chloride in the solution. The curves are

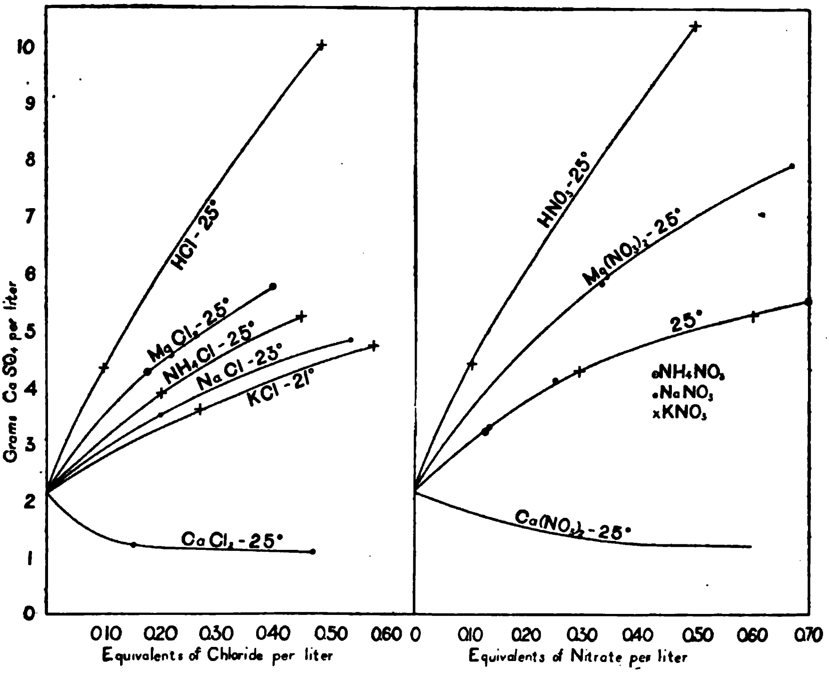

FIG. 9.—Solubility of calcium sulphate in chloride and nitrate solutions.

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[a] Bul. Soc. Chim. (2), 9, 441 (1868).

for 25° in all cases for which the data was available, but where such was not available temperatures very close to 25° were taken; in the case of sodium chloride 23° and in the case of potassium chloride 21°. It is probable that if the result had been available at 25° the curves would have occupied a slightly higher position in the diagram. A similar figure has been drawn for the nitrates of hydrogen, magnesium, ammonium, sodium, and potassium. The position which these curves occupy relatively to one another is very interesting. The acids in both cases lie far above any of the salts, then the magnesium salts, and then the ammonium, sodium, and potassium, all together in the case of the nitrates, but separate in the case of the chlorides. This is probably due to the differences in temperature. From this it would appear that the solvent action of the positive ions investigated is greatest in the case of the hydrogen ion, somewhat less in the case of the magnesium ion, and least in the case of the sodium, potassium, and ammonium ions, which are of about the same power.

Comparing the chloride and nitrate of each metal, it will be seen that the nitrate possesses a slightly greater solvent action on gypsum than does the chloride.

Just as any of the physical properties of a dilute solution of a salt is the sum of the physical properties of the ions, the solvent action of these ions on a salt of comparatively low solubility is an additive property depending on the water and the two ions. In this way, if the data were determined with a high degree of accuracy, the difference between the solvent powers of every pair of cations might be accurately found, also the difference between the solvent power of every pair of anions. Thus, knowing the solvent action of $NaCl$, KCl, and $NaNO_3$, the solvent action of KNO_3 might be computed.

In the case of the sulphates, the course of the curve, which falls with increase of the amount of the sulphate, has not been determined at low enough concentration to allow of any generalization.

In all the cases of the nitrates and the chlorides the course of the curve rises with addition of the other salt and passes through a maximum. This is what might be expected, for the concentrations of the calcium ion and of the sulphion are constantly increasing.

THE SOLUBILITY OF CALCIUM SULPHATE IN SOLUTIONS OF NONELECTROLYTES.

Alcohol.

The experiments of Magnanini[a] show that gypsum is made less soluble in a 10 per cent alcohol solution than in water.

Sugar.

In an early paper on the solubility of gypsum in sugar solutions Sostmann[b] has pointed out that a 67 per cent of sugar will dissolve

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[a] Gazz. chim. ital., **31** ii, 542 (1901).

[b] Zeit. Rübenzuckerindustrie, **16**, 517 (1866).

0.163 per cent $CaSO_4$, or, in other words, there is present 0.494 gram of $CaSO_4$ to 100 grams of water. Gypsum is more soluble in water containing sugar than in an equivalent amount of water. This result does not agree well with the results of Stolle,[a] whose results are given in Table LII.

TABLE LII.—*Solubility of calcium sulphate in sugar solutions at different temperatures.*

Per cent sugar.	Quantity of $CaSO_4$ in 100 grams sugar solution.					
	At 30° C.	At 40° C.	At 50° C.	At 60° C.	At 70° C.	At 80° C.
	Gram.	*Gram.*	*Gram.*	*Gram.*	*Gram.*	*Gram.*
0	....	0.2162	0.1733	0.1733	0.1655	0.1710
10	0.2045	.1733	.1733	.1576	.1576	.1613
20	.1811	.1655	.1421	.1382	.1421	.1263
27	.1557	.1440	.1363	.1285	.1285	.0972
35	.1265	.1051	.1089	.1109	.0915	....
42	.1031	....	.0777	.0817	.0856	.0729
49	....	.0564	.0739	.0564	.0603	.0486
55	....	.0886	.0505	.0486	.0369	.0330

This table shows that with increasing concentration the solubility of gypsum tends to decrease in sugar solution above 30° and also that the solubility in a given weight of solution decreases with increasing content of sugar.

Glycerine.

The solubility of gypsum in glycerine is given by Asselin[b] as 0.957 part in 100 parts glycerine, at ordinary temperatures, the solubility increasing with the temperature.

CALCIUM SULPHATE IN SALT DEPOSITS AND IN ALKALI REGIONS.

The salts composing the accumulations known as "white alkali" are the same as those found in sea water. A great deal of work has been done on solutions containing these salts, especially for the purpose of elucidating the processes which have led to the deposition of salt deposits, and it is now possible to obtain a clear idea of the general features and characteristics of the system formed by calcium sulphate in contact with a solution of these several salts. This is the more readily done, since in a recent publication van 't Hoff[c] has summarized a large portion of the work upon the deposition of salts from solutions containing the salts present in sea water. As the salt deposits have been laid down by the constant evaporation of sea water, a knowledge of the conditions under which each salt separates will indicate the conditions which obtained in nature during the deposition. The salts present in sea water and in "white alkali" are mainly the chlorides and sulphates of sodium, potassium, and magnesium. Calcium salts are present, for calcium appears in deep salt deposits as anhydrite and in surface deposits as gypsum. The influence of the presence of calcium will be discussed after a consideration of the other salts.

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[a] Zeit. Rübenzuckerindustrie, **37**, 321 (1900).

[b] Compt. rend., **76**, 884 (1873).

[c] Zur Bildung der ozeanischen Salzablagerungen, Braunschweig, 1905.

Let us first consider the number of components in a solution containing the chlorides and sulphates of sodium, potassium, and magnesium. Apparently there are seven—water, NaCl, Na_2SO_4, KCl, K_2SO_4, $MgCl_2$, and $MgSO_4$. But there are two possible relations existing among these, so that the number can be considered as reduced to five. The relations are that magnesium sulphate and potassium sulphate may be expressed in terms of the other salts, thus,

$$MgSO_4 = MgCl_2 + Na_2SO_4 - 2NaCl.$$
$$K_2SO_4 = 2KCl + Na_2SO_4 - 2NaCl.$$

The phase rule requires that under no circumstance can the number of phases exceed the number of components by more than two. The maximum number of phases that can exist under equilibrium conditions is, therefore, seven. The coexistence of seven phases is possible, however, only at definite temperatures, and for any temperature in general the maximum number of phases that can exist is six.

There is present in sea water and generally in "white alkali" a predominating amount of sodium chloride, and in salt mines there is found sodium chloride in all layers, which has crystallized out with one or more other salts. Van 't Hoff has imposed the condition in all his experiments that the solution shall be saturated with sodium chloride, or in other words that sodium chloride shall be always present as a solid. In his experiments the solution and the vapor are two other phases, leaving a maximum possibility of three other solid phases, unless the temperature happens to be that of a univariant system, in which case there will be four other solid phases.

In the solution there may be any or all of six salts, one of them always being sodium chloride. As was stated above, there are two relations between these six quantities, making four the least number of variables in which the concentration may be expressed. In stating the results of the analyses of the solutions, van 't Hoff has adopted two arbitrary conventions—first, as the amount of potassium never exceeds the amount of chloride, the potassium shall always be expressed as potassium chloride; and second, all the remaining chlorine is considered as sodium chloride (NaCl), unless chlorine be in excess over sodium, in which case all the sodium is expressed as sodium chloride. Thus the greatest amount of sodium chloride possible is considered to be present. The residue is expressed as sodium sulphate (Na_2SO_4) and magnesium sulphate ($MgSO_4$), or as magnesium chloride ($MgCl_2$) and magnesium sulphate ($MgSO_4$), as the case may be.

All the possible solutions as given by van 't Hoff are expressed in terms of NaCl, KCl, $MgSO_4$, and Na_2SO_4, or in terms of NaCl, KCl,

$MgSO_4$, $MgCl_2$, and it is necessary, therefore, to use two diagrams or sets of axes in order to represent all the conditions. Two diagrams have been joined, as indicated in figure 10. The solutions represented by the one set of variables are plotted with $MgCl_2$ concentrations for abscissas and $(K_2Cl_2-MgSO_4)$ concentrations for ordinates, and the solutions represented by the other set of variables are plotted with Na_2SO_4 concentrations as abscissas and $(K_2Cl_2-MgSO_4)$ concentrations for ordinates.

The procedure adopted by van 't Hoff and his coworkers has been to determine what solid phases could appear at 25° C., and then to determine the range of concentrations of the solution within which each one exists. The phase rule prescribes the maximum number of phases which may exist if there are a given number of components present, the conditions being known as invariant. These invariant points have been found—i. e., the compositions of the "constant" solutions have been determined. In the following table the composition of these solutions have been given. For instance, at the point **O**, in figure 11, the only salt present is sodium chloride, and the invariant point at 25° is the solution saturated with this salt; at the point **A** the salts are magnesium chloride and sodium chloride, and the composition of the solution saturated with both these salts is given in the table. At any other point on the diagram, **P** for instance, there are present as solids kainite, leonite, and sylvine, and the composition of this solution in equilibrium with these three solids has been given in the table. The significance of the column headed by "$CaSO_4$" will be discussed later.

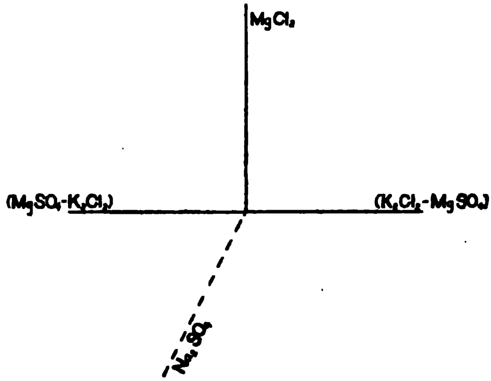

FIG. 10.—Coordinates used in figure 11.

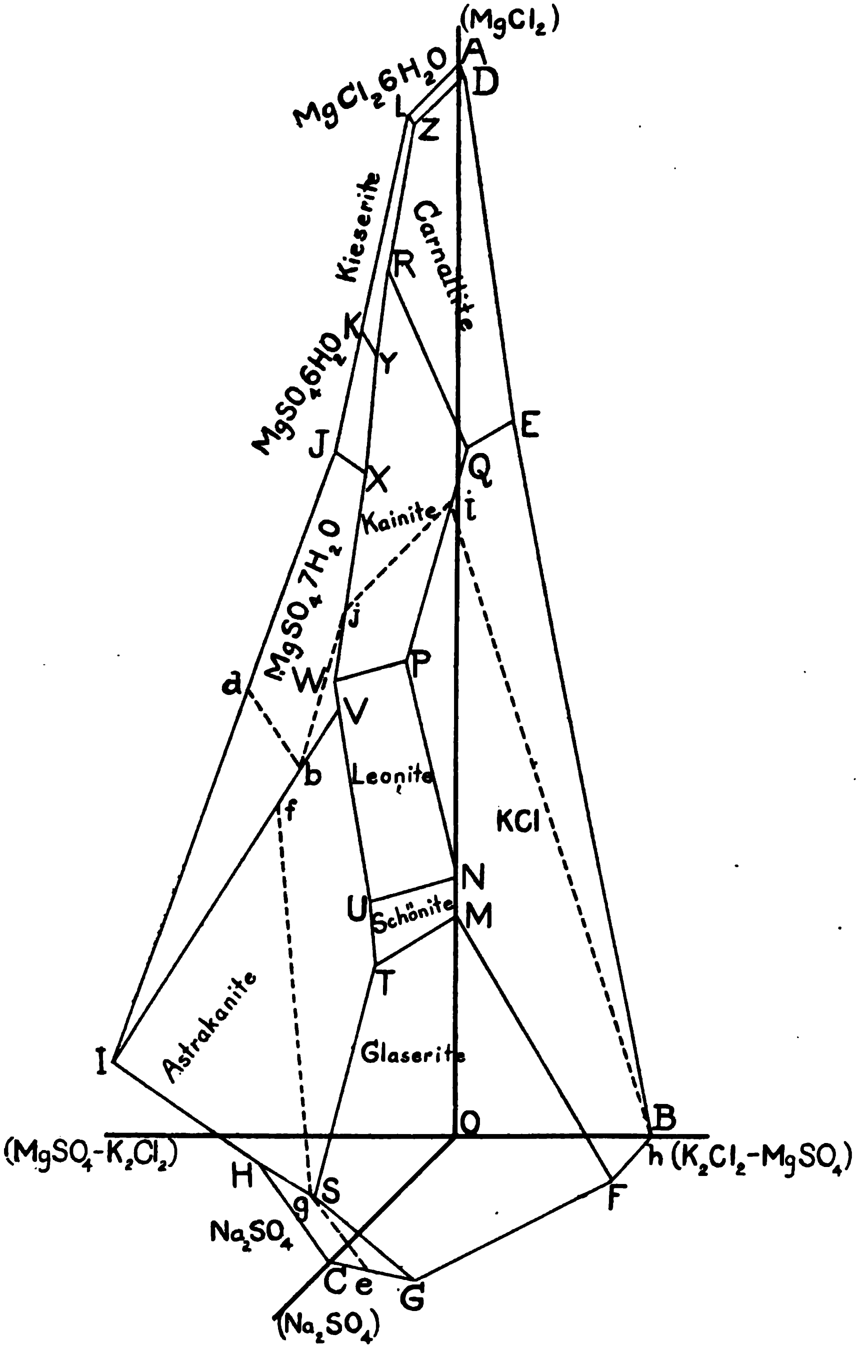

FIG. 11.—Diagram showing the mutual solubilities of the salts present in the sea-water deposits.

TABLE LIII.—*Composition of solutions at "constant" or invariant points on the diagram (fig. 11) at 25° C.*

Corresponding points on diagram.	Solids with which "constant" or invariant solutions are saturated, sodium chloride always being present.	Quantity of several salts in 1,000 mols. of H_2O solution.						Vapor pressure of the solution.
		Na_2Cl_2.	K_2Cl_2.	$MgCl_2$.	$MgSO_4$.	Na_2SO_4.	$CaSO_4$.	
		Mols.	*Mols.*	*Mols.*	*Mols.*	*Mols.*	*Mols.*	*Mm.Hg.*
O		55.5					0.86	17.7
A	$MgCl_2.6H_2O$	1		106			.39	7.6
B	KCl	44.5	19.5				.94	16.8
C	Na_2SO_4	51				12.5	.05	17.5
D	$MgCl_2.6H_2O$, carnallite	1	.5	105			.38	7.5
E	KCl, carnallite	2	5.5	70.5			.26	12.7
F	KCl, glaserite	44	20			4.5	.03	16.8
G	Na_2SO_4, glaserite	44	10.5			14.5	.02	17
H	Na_2SO_4, astrakanite	46			16.5	3	.04	17.1
I	$MgSO_4.7H_2O$, astrakanite	26		7	34		.0	15.1
J	$MgSO_4.7H_2O$, $MgSO_4.6H_2O$	4		67.5	12		.19	12.2
K	$MgSO_4.6H_2O$, kieserite	2.5		79	9.5		.12	10.8
L	Kieserite, $MgCl_2.6H_2O$	1		101	5		.25	7.5
M	KCl, glaserite, schönite	23	14	21.5	14		.08	15.9
N	KCl, schönite, leonite	19.5	14.5	25.5	14.5		.09	15.7
P	KCl, leonite, kainite	9.5	9.5	47	14.5		.13	13.4
Q	KCl, kainite, carnallite	2.5	6	68	5		.24	12.4
R	Carnallite, kainite, kieserite	1	1	85.5	8		.13	9.5
S	Na_2SO_4, glaserite, astrakanite	42	8		16	6	.06	16.6
T	Glaserite, astrakanite, schönite	27.5	10.5	16.5	18.5		.08	16.1
U	Leonite, astrakanite, schönite	22	10.5	23	19		.08	15.7
V	Leonite, astrakanite, $MgSO_4.7H_2O$.	10.5	7.5	42	19		.1	14.5
W	Leonite, kainite, $MgSO_4.7H_2O$	9	7.5	45	19.5		.09	13.4
X	$MgSO_4.7H_2O$, kainite, $MgSO_4.6H_2O$.	3.5	4	65.5	13		.2	12.2
Y	$MgSO_4.6H_2O$, kainite, kieserite	1.5	2	77	10		.21	10.8
Z	Carnallite, $MgCl_2.6H_2O$, kieserite.	1	.5	100	5		.15	7.4

The possible minerals which may appear by allowing a solution of the sulphates and chlorides of magnesium, potassium, and sodium to crystallize at 25° are given in the following table. The table gives also the composition of these minerals and the field in diagram (fig. 11) within which they exist.

TABLE LIV.—*Chemical composition and field within which each solid phase exists.*

Mineralogical name.	Solid phase.	Field.
Bischofite	$MgCl_2.6H_2O$	A L Z D.
Sylvine	KCl	B F M N P Q E.
Thenardite	Na_2SO_4	C G S H.
Carnallite	$MgCl_2.KCl.6H_2O$	D Z R Q E.
Glaserite	$2K_2SO_4.Na_2SO_4$	F H T S G.
Astrakanite	$Na_2SO_4.MgSO_4.4H_2O$	S H I V U T.
Reichardtite	$MgSO_4.7H_2O$	J X W V I.
	$MgSO_4.6H_2O$	J X Y K.
Kieserite	$MgSO_4.H_2O$	K Y R Z L.
Schönite	$MgSO_4.K_2SO_4.6H_2O$	T U N M.
Leonite	$MgSO_4(K, Na)_2SO_4.4H_2O$	N U V W P.
Kainite	$MgSO_4.KCl.3H_2O$	P W X Y R Q.

The vapor pressures of the solutions at the various points in the figure have been determined at 25°, and in this way the path along which the concentration of the solution during evaporation will move has been determined. During evaporation at constant temperatures the end-point in the evaporation will be that solution which has the lowest vapor pressure. The paths along which the solution moves have been determined by van 't Hoff and his coworkers. It has been found that the end-point is **Z**, at which carnallite, kieserite, and bischofite crystallize out together. It should be noticed that in the evaporation of sea water the first solid which separates is gypsum, the solution being so dilute at first that gypsum and not anhydrite is the stable phase, then sodium chloride appears in quantity. The first mineral composed of the other salts is kainite, the solution being represented in the diagram by a point in the kainite field near the line **R Y**. At this point the stable phase containing calcium is anhydrite, and in all subsequent crystallization from these concentrated solutions anhydrite is to be expected. By further evaporation a point on the line **R Y** is reached, at which both kainite and kieserite separate until **R** is reached. Then kieserite and carnallite separate until the point **Z** is reached, and finally the three phases, kieserite, carnallite, and bischofite. The same phases, sodium chloride, kieserite, carnallite, and bischofite are also the final products when sea water is evaporated at 83°. Several other salt layers are actually formed, polyhalite ($K_2SO_4.MgSO_4.2CaSO_4.2H_2O$) and langbeinite ($2MgSO_4.K_2SO_4$). The alternate layers of anhydrite and common salt are probably due to the varying temperature at which the salt layers have been deposited. For instance, anhydrite is less soluble, while sodium chloride is somewhat more soluble, in hot water than in cold. Thus, during a warm season anhydrite would crystallize out, and when the solution became colder sodium chloride would crystallize out. At the surface anhydrite would gradually be transformed into gypsum by taking up water from the atmosphere.

The introduction of one more component to the system will in general alter the whole situation. But the introduction of the salt calcium sulphate ($CaSO_4$) to the solution has very little influence on the position of any point in the diagram, because the amount of calcium sulphate in solution is very small, and this very small amount does not alter appreciably the solubility of the other salts. The amount of calcium sulphate in solution and corresponding to each of the points in the diagram is given in Table LV. Therefore practically the same state of affairs exists as before the addition of the calcium sulphate, except for the fact that one more phase may appear, a phase containing calcium sulphate. Consequently another set of fields is superimposed on the double diagram representing the solid phases which contain calcium sulphate. These fields are three in number and are marked out by broken lines—the field **L d b j i h B A**, in which anhydrite ($CaSO_4$) is the solid phase, the field **d b g e C I**, in which glauberite ($CaSO_4.Na_2SO_4$) is the solid phase, and the field **e g f j i h G**, in which syngenite ($CaSO_4.K_2SO_4.H_2O$) is the solid phase. It will be observed that anhydrite is the stable solid phase in the part of the field where the evaporation of sea water is represented, and hence anhydrite is practically the only form in which calcium sulphate appears in the deep salt deposits.

The concentration of the solutions at the various points along these new boundary lines are given in the following table:

TABLE LV.—*Composition of solutions containing calcium sulphate at "constant" or invariant points on the diagram at 25° C.*

Corresponding points on diagram (fig. 11).	Solids with which "constant" or invariant solutions are saturated, sodium chloride always being present.	Quantity of salts in 1,000 mols. of H_2O.						Vapor pressure of the solution.
		Na_2Cl_2.	K_2Cl_2.	$MgCl_2$.	$MgSO_4$.	Na_2SO_4.	$CaSO_4$.	
		Mols.	*Mols.*	*Mols.*	*Mols.*	*Mols.*	*Mols.*	*Mm. Hg.*
b	Anhydrite, glauberite, syngenite, $MgSO_4.7H_2O$, astrakanite	18.5	5	36	20	....	.08	14.4
d	Glauberite, anhydrite, $MgSO_4.7H_2O$	....	....	....	....	....	.1	14.4
e	Glauberite, syngenite, Na_2SO_4	47	5.5	....	....	14	.03	17.3
f	Glauberite, syngenite, astrakanite, $MgSO_4.7H_2O$	14.5	5.5	32.5	23	....	.07	14.4
g	Glauberite, syngenite, astrakanite, Na_2SO_4	41.5	8.5	....	16.5	5.5	.06	16.6
h	Syngenite, anhydrite, KCl	46	19.5	....	....	....	.85	16.8
i	Syngenite, anhydrite, kainite, KCl	4.5	7	62.5	7.5	....	.21	12.7
j	Syngenite, anhydrite, kainite, $MgSO_4.7H_2O$	7	6.5	52	17.5	....	.13	12.9

More recently[a] the existence of two other fields has been proved, but these are very small and are not represented in the diagram. The boundary for the phase polyhalite ($K_2SO_4.MgSO_4.2CaSO_4 2H_2O$) has been found to cut a small portion from the field for syngenite. It passes through **b** around the points **W** and **V** and cuts the line **f g** near **f**. Another small field is a long, narrow strip bounded by **i**, **h**, and points in **i j** and **h f** near **i** and **h**, respectively. In this field the stable phase is potassium pentacalcium sulphate ($K_2SO_4.5CaSO_4.H_2O$).

Gypsum ($CaSO_4.2H_2O$) is the solid phase in a very small field just at the point **h**, cutting off a very small portion from the field for anhydrite[b], and a field for krugite ($4CaSO_4.K_2SO_4.MgSO_4.2H_2O$) cuts off a very thin portion of the anhydrite field just at the point **j**.

If instead of the crystallization of a brine we follow the course of the washing out of a mixture of salts by water, the composition of the solution which results will depend only on the solid phases which are present and not on their relative amounts. When any one of the solid phases becomes completely washed out, the composition of the solution will change. This washing-out process has been followed by this Bureau and analyses of the drainage water of the Swan tract near Salt Lake City have been tabulated at intervals extending over three years. The accumulation of alkali at the surface of soils is due mainly to the evaporation of seepage waters from lower levels. These seepage waters will in all probability have a constant composition as the water has become saturated with respect to all the constituents of the salts in the lower depths. In the converse process of washing out the solution should have a constant composition throughout. This has actually been found to be the case in the Swan tract, where the percentage of alkali salts in the soil has decreased as a result of flooding from more than 2.7 per cent to less than 0.3 per cent. The composition of the drainage water has, however, remained approximately constant throughout the whole period.

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[a] Van 't Hoff and Farup, Sitzungsber. Akad. Wiss. Berlin (1903), 1,000; van 't Hoff and Voerman, ibid. (1904), 984; van 't Hoff, ibid. (1904), 935.

[b] Van 't Hoff, Zeit. anorg. Chem., 47, 244 (1905).

Of course the composition will depend upon the temperature and therefore on the season, and also, as calcium sulphate goes into solution at a very slow rate indeed, the composition of the drainage water will depend on the time of contact of the irrigation water with the soil. These results have been given on page 10 of this bulletin.

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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 34.
MILTON WHITNEY, Chief.

RECLAMATION OF ALKALI SOILS.

BY

CLARENCE W. DORSEY.

WASHINGTON:
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1906.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., March 23, 1906.

Sir: I have the honor to transmit herewith, and to recommend for publication as Bulletin No. 34, the manuscript of an article on Reclamation of Alkali Soils, prepared by Mr. Clarence W. Dorsey, of this Bureau. The preparation of this paper was suggested by the increasing interest taken in the alkali reclamation experiments now in progress in several parts of the arid West under the direction of this Bureau, and is designed to meet the constant inquiries for full information on this all-important Western problem.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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RECLAMATION OF ALKALI SOILS.

INTRODUCTION.

A problem of paramount interest in many irrigated districts in the arid States is the successful treatment of alkali soil. With the practice and extension of irrigation, damage has been caused by the rise and spread of alkali. Few districts are entirely free from this damage, while in many the trouble increases from year to year. It is estimated that in about 10 per cent of the areas in the irrigated districts surveyed by the Bureau of Soils alkali is more or less a serious menace to agriculture. In certain localities successful farms of a few years ago are now abandoned, flourishing fields have been transformed into barren alkali flats, and land values have greatly depreciated, all on account of alkali. In discussing the subject many questions naturally arise: What is alkali; how has it accumulated in the soils; can its accummulation be prevented; having excessive quantities in the soil, can it be removed and the soil restored to its original fertile condition?

DEFINITION OF ALKALI.

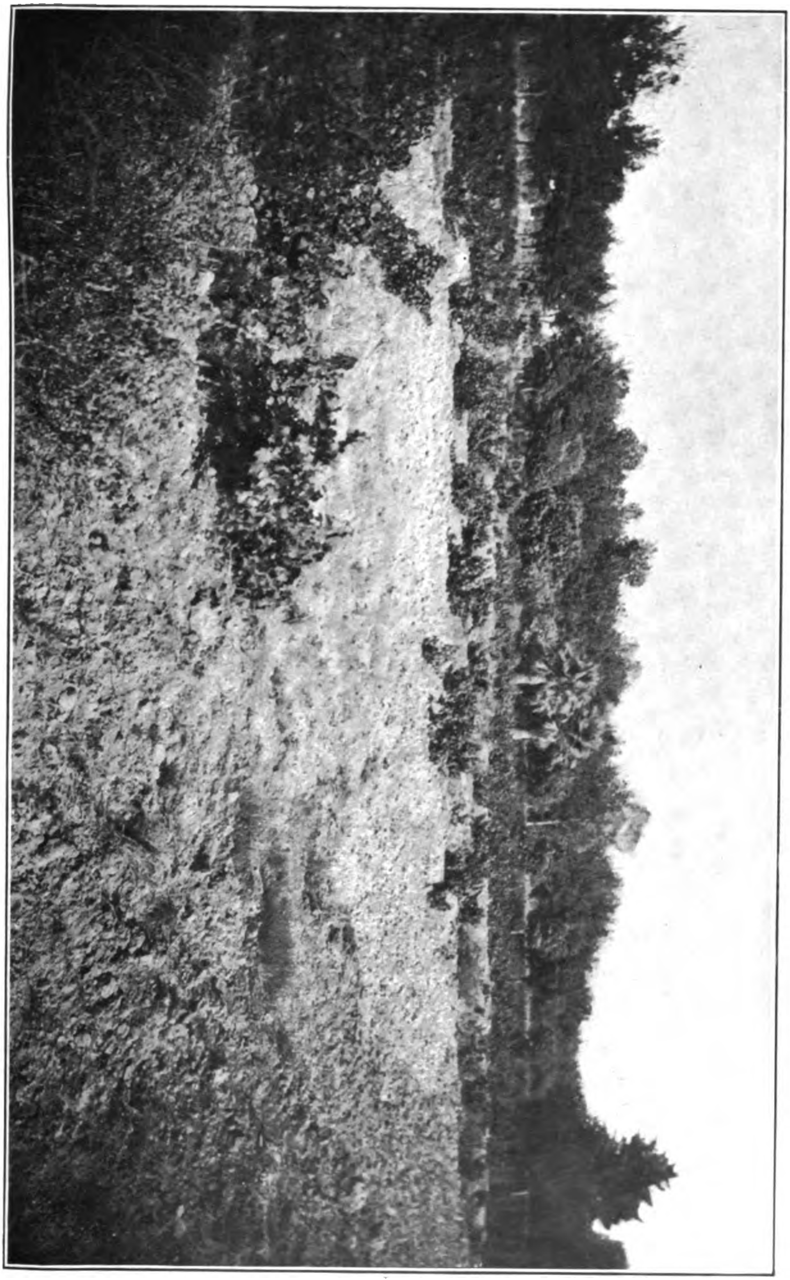
The term "alkali," as commonly used in arid and semiarid regions, refers to accumulations of water-soluble mineral salts. The principal substances composing alkali consist of chlorides, sulphates, and carbonates of sodium, magnesium, and calcium, or a mixture of two or more of these salts. Other substances may be found, but they are relatively unimportant. Generally speaking, alkali consists of three principal ingredients—sodium chloride or common salt, sodium sulphate or Glauber's salt, and sodium carbonate or sal soda. Alkali is commonly spoken of as white alkali and black alkali, depending on the appearance of the incrustations caused by excessive accumulation on the surface. Usually when large quantities of sodium sulphate or sodium chloride accumulate on the surface its presence is marked by a white incrustation, hence the term in common use—white alkali. Since sodium carbonate, when present in considerable quantities, corrodes the vegetable matter of the soil, forming a brown or dark stain, it is called black alkali. As calcium chloride, a comparatively harmless salt, may likewise impart a dark stain to the soil, it is evident that this classification is not altogether satisfactory, though it will probably always continue in local use.

ORIGIN OF ALKALI.

The soils of arid regions, as compared with those found in humid regions, are by far the richer in water-soluble mineral salts. During the processes of soil formation many changes take place before huge bowlders and rock masses are converted into soils capable of supporting vegetation. Freezing and thawing, and the action of the winds, rains, water, and ice, in the course of time reduce rocks to the more finely divided particles that finally constitute a soil in the true sense of the word. The minerals composing the original rock are broken apart and the chemical changes incidental to rock weathering set free quantities of soluble salts. Whether these salts remain in the soil depends on the amount and distribution of the rainfall of the region. In countries having an abundant rainfall the greater part of these soluble mineral salts is leached away, but in regions of limited rainfall most of these salts remain in the soil. Much of this soluble material constitutes the alkali of arid regions, and so in many places we can trace the origin of the alkali directly to the rocks which have weathered into soils. As a general rule, we find that in regions having a rainfall of less than 20 inches more or less alkali is present, while with a rainfall greater than 20 inches the tendency for such accumulation is materially lessened. In some places the origin of the alkali is due to the evaporation of bodies of sea water that have been cut off by various causes. East of the ninety-ninth meridian alkali is frequently found, but the rainfall is usually so great that the alkali question does not assume the importance it has in States farther west.

ACCUMULATION OF ALKALI.

Since the salts composing alkali are readily soluble in water, it is evident that, while they will remain stationary in a dry soil, when water is added they will be dissolved and move within the soil in whatever direction the water moves. Farmers living in an arid region are perfectly familiar with this phenomenon. They have noticed that places heavily incrusted with alkali show no such crusts after heavy rains or the application of irrigation water. The alkali dissolves in the water and with it soaks into the soil, but as the soil dries out it again makes its appearance on the surface. This is because the greater part of the water added by the rains or irrigation returns through evaporation to the surface, and when it evaporates all of the dissolved salts are again deposited on the surface. Many farmers in a new irrigation district have found to their sorrow that after a few years of irrigation alkali has appeared where they little imagined it was present. In such cases the appearance of alkali is due to the fact that the irrigation waters have penetrated to the deep subsoil, dissolvi[illegible]e stores of soluble salt held there. Subsequent



FIRST APPEARANCE OF ALKALI IN A VINEYARD NEAR FRESNO, CAL.

The former uniform growth of vines is being destroyed as the alkali conditions grow worse from year to year.

evaporation of much of this water at the surface deposits the salts dissolved from the entire column of soil. If sufficient water were added not only to start a downward movement of the salts, but also to leach them away into the country drainage, the soil would then be entirely free from such accumulations.

In most irrigated districts just such changes have been brought about, and as a matter of fact most of the accumulations of alkali in cultivated fields are due to the local concentration caused by the irrigation water carrying the soluble alkali from one part of a district to another. Usually the alkali is removed from higher-lying to lower-lying areas where, on account of the low position, there is a tendency for the drainage waters to collect. In such areas the underlying subsoil is filled with water until capillary connection between the subsoil and the surface is established. By continued evaporation of this capillary water the soluble salts are deposited at or near the surface. In many areas such accumulations would never have taken place had precautions been taken to provide the necessary drainage at the time the irrigation canals were built. Unfortunately in most irrigated districts no such precautions were taken, as at that time the country was suffering from a lack of water and no thought was given to the future drainage of the district. Irrigation canals and ditches are made to furnish the water needed to grow crops. At this time the ground water is usually many feet below the surface. Alkali may be present in small local spots, but usually such places are small and considered unimportant. As irrigation is continued, water gradually accumulates in the lower places, and these places gradually increase in size while accumulations of alkali also begin to appear. Even then no provisions are made for drainage and the damage resulting from the rise of the ground water and alkali accumulations continues to increase until in many districts the choicest farm lands are thrown out of cultivation.

EFFECT OF ALKALI ON CROPS.

When any considerable quantity of alkali is present in soils it exerts a toxic or poisonous influence on the crops. (See Pl. I.) Not all plants are affected alike by alkali, for it is well known that some can withstand quantities of alkali that would be fatal to others, nor are the various kinds of alkali equally injurious to the different crops.

Certain plants, on account of their immunity to relatively high concentrations of alkali, have come to be known as resistant, while others more easily injured are classed as sensitive. Among the resistant cultivated plants are certain varieties of barley, sorghum, and sugar beets, while corn and wheat furnish examples of more sensitive crops. Alfalfa in its younger stages is sensitive to alkali, but when once well established becomes quite resistant. Certain weeds and native plants (such as salt grass, greasewood, and the saltbushes) indicate the presence of alkali in the soil, even though no traces may appear on the surface. Sage brush and rabbit bush are generally supposed to denote alkali-free soils. Frequently the native vegetation is used as a guide in selecting soils in new districts and is generally to be relied upon.

Of the different classes of alkali, sodium carbonate, or black alkali, is considered the most injurious. Laboratory experiments have shown that magnesium chloride and sulphate are equally if not more injurious than sodium carbonate. After these salts comes sodium chloride (ordinary salt), and last sodium sulphate. When present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate represents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops, and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position. As the alkali conditions in a soil may change from day to day, depending on the moisture present in the soil, it is exceedingly difficult to determine the exact amounts of total salts that any given crop can withstand. Again, since there is generally an admixture of the various salts present in the soil, we seldom have an opportunity to study the effect of any single salt on crop growth. Enough is known to establish the approximate accuracy of the effects of the three salts as given above. The fact that a plant is growing in soil heavily incrusted with alkali does not necessarily mean that the plant at any time came in contact with so much alkali. Rains or irrigation may leach the alkali from the upper few inches of soil, thus enabling the planted seed to germinate freely. As the roots develop and penetrate deeper for moisture and food supply, the alkali may slowly accumulate at the surface in such a manner that the plant is not affected.

The first apparent effect of alkali is in retarding germination. Usually the vitality of the seed is not affected, and if water subsequently leaches the alkali below the seeds will then germinate. Of course, if the alkali content remains unchanged no germination will take place in soils carrying considerable alkali. (See Pl. II.) In case much black alkali is present the effects are very pronounced. This salt has the power actually to decompose seeds as well as growing plants and has been known to destroy completely the hard outer bark of mature trees.

METHODS OF PREVENTING ALKALI ACCUMULATIONS.

In many districts where alkali is rapidly spreading, the farmer is chiefly concerned with any course of treatment that will prevent excessive quantities from accumulating in his soil. Slight amounts of alkali do not harm crops, but probably exert a beneficial action upon them, so that the farmer's first interest is to check accumulation beyond the limit of safety. Economy in the use of irrigation water is the first step to be taken. By using as little water as possible the farmer postpones, perhaps indefinitely, the time when the water table shall rise sufficiently high to cause surface accumulations of alkali. With a constantly rising water table, not only is the accumulation of injurious salts accelerated, but the deep-rooted crops and orchard trees are injured or killed by the excess of water. Many fine fields of alfalfa have been entirely ruined by using excessive quantities of water. The ground water, already dangerously near the surface, is further raised, capillary connection is established, and with the evaporation of at least a portion of this water conditions are made extremely favorable for the final abandonment of the field as a result of excessive alkali accumulation. Supplying to the crops only sufficient water for their growth is one method, then, of actually preventing accumulations of alkali beyond the danger point.

The above remarks apply where the soil is reasonably free from alkali and the irrigation water is of good quality, but where there is already a large accumulation of salts economy in the use of irrigation water is one of the worst methods. When the soil contains a relatively large amount of salt and but little water containing much salt is frequently applied, the ordinary evaporation will increase the salt content of the soil to such an extent that crops can no longer survive, whereas if adequate drainage is provided and a large amount of water is used the excess of salt resulting from the evaporation of previous applications of water may be removed and the soil moisture be maintained at nearly the same concentration as the water supply.

As bearing upon this subject it is important to refer to the practice of Arabs in the Desert of Sahara in eastern Algeria. Thomas H. Means, formerly of this Bureau, visited that country in 1902. He found, in addition to the cultivation of the resistant date palm, that large quantities of deciduous fruits, garden vegetables, and alfalfa are produced. Many of the crops grown are quite sensitive to alkali, and yet they were being irrigated with water containing in some instances as much as 800 parts of soluble salts to 100,000 parts of water. Sometimes as high as 50 per cent or 400 parts of the salts found in the irrigation water were sodium chloride. This is greatly in excess of the limit of concentration for irrigation water, which by some authorities has been placed at from 200 to 300 parts per 100,000.

The manner in which irrigation water containing such large quantities of saline matter is used is described as follows by Means in Circular No. 10 of this Bureau:

> The prerequisite to the use of water of high salt content in irrigation is the knowledge that the methods employed are opposed to the teachings of most American writers on the

subject. Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

The methods in the oases are quite different. The Arab gardens are divided into small plots about 20 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained. There is little opportunity for the soil water to become more concentrated than the water as applied, and the interval between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

The natives not only have the question of very saline irrigation waters to contend with, but the soils originally are often very alkaline. In three years they reclaim land too salty to grow the minor crops, using the saline water for that purpose, following the same plan of drainage and weekly irrigation as where crops are growing.

Surface irrigation as opposed to subirrigation is another important question to be considered on soils where there is any liability to alkali accumulation. By applying all water to the surface whatever salts may have accumulated there are dissolved and carried downward into the soil to the depth penetrated by the irrigation water. This insures a downward movement of the salts each time the field is irrigated. With subirrigation the water is supplied at some point below the surface, where it dissolves the salts contained in the soil with which it comes in contact. Since some of this water eventually reaches the surface by evaporation, just so much salt will be deposited there as is contained in the subirrigation water brought up by capillary action. Subsequent applications of water by subirrigation by dissolving more salt tend to increase still further the quantity of salts deposited on the surface.

By many it will be regarded that the evil effects of subirrigation have been greatly overestimated; that the good effects more than conterbalance possible injury which may follow. It is true that subirrigation in many cases is practiced where sufficient water is not always available for surface irrigation, and that the greatest economy in the use of water is possible by this method. But even these objections do not disprove the statement that the invariable result of subirrigation is to eventually deposit at or near the surface the greater part of the salts contained within the zone of soil moistened by the subirrigation water. In many cases years have elapsed before sufficient alkali has accumulated within the upper few inches of soil to injure crops, but more often the damage ensues within a few years after subirrigation is practiced. Perhaps one of the most prominent instances of alkali accumulations caused by subirrigation is in portions of the San Joaquin Valley, California. Here large areas of once fertile soil have been ruined by the rise of black alkali, largely as the result of the practice of subirrigation and the consequent fluctuating of the water table. The ground water rises rapidly after water is turned into the canals each spring. The loss of water from the canals by seepage is enormous on account of the sandy soils through which they pass. In spite of the frequent cultivation given the soils some water is evaporated at the surface and its dissolved salts deposited there. Applying water upon the surface early in the spring, when the water table is still several feet deep, would insure a downward movement of the alkali accumulated near the surface during the previous year. Then by reducing surface evaporation as far as possible by cultivation the salts might be held in the lower depths of soil.

Even irrigating by furrows is one form of subirrigation that allows whatever salts are contained in the soil to be deposited at the tops of the slight ridge caused by the furrow. In case furrow irrigation is the best, and it is often the only method available, occasional smoothing of the surface and flooding the entire field greatly helps to check the accumulations caused by continued furrow irrigation.

In this connection it seems advisable to insist on thorough smoothing or leveling of the surface before irrigation. In too many cases not enough care is given to the initial preparation of the land; that is, before any cultivation is begun. The farmer, anxious to get returns on new land with the least expenditure of time and labor, often neglects thoroughly to level his land at the outset. He realizes that there are still high spots in the field that water will not reach, but hopes eventually to complete the leveling, in the meantime relying on the lateral movement of the water to moisten the higher portions of the field. As a result, when the lower, more level parts of the field are irrigated, the water creeping up to the high spots evaporates there, and in the course of time deposits excessive quantities of alkali. Frequently from these high spots the alkali slowly spreads until it becomes a serious menace to the entire field. All this could have been avoided by thoroughly leveling the field in the beginning, so as to insure an even flow of water over the entire field.

The next important consideration in preventing excessive alkali accumulations at or near the surface is to restrict as far as possible surface evaporation. With all irrigation water applied to a carefully leveled surface it is evident that the salts will be leached downward, and can only return to the surface upon evaporation of the soil moisture. Any method of treatment, then, that prevents evaporation necessarily retards the rise of the alkali. If evaporation were entirely eliminated there could be no surface accumulation of alkali. Unfortunately, however, we can not entirely prevent evaporation, although we can in a measure control it. Cultivation, mulching with straw or leaves, or shading the surface by crops tend to restrict surface evaporation. Frequent shallow cultivation by keeping the upper few inches of soil in a loose condition breaks the ascending column of capillary water, and thereby reduces the quantity of water that can reach the surface. Scattering leaves or straw protects the surface from the direct rays of the sun and also reduces evaporation. In many cases retarding evaporation by mulching the surface in this manner is hardly practicable on account of the cost, although it is quite effective. Frequently in the spring, after the winter rains have washed the alkali a short distance below the surface, it is possible to secure a stand of rapid growing crops that will furnish a dense shade by the time hot weather comes on. Many cases are on record where land containing appreciable quantities of alkali have been utilized in this manner. The shade furnished by the crop checks excessive evaporation, while frequent surface irrigations still further operate to drive the alkali into the lower depths of soil. While there are undoubtedly many cases where excessive quantities of salts will accumulate in the soil in spite of the utmost precautions, it is believed that much good can be accomplished by paying attention to some of the above considerations.

TREATMENT OF ALKALI SOILS.

We must now consider what use can be made of soils containing excessive quantities of alkali. Can their reclamation be accomplished, and if reclaimed can they be successfully farmed? Is it really necessary to reclaim them? Can not some revenue be derived from them in their present condition? For convenience the treatment of alkali soils may be discussed under the following heads: (*a*) Cultivation of alkali-resistant crops; (*b*) use of chemical antidotes; (*c*) removing alkali from the soil by various methods.

CULTIVATION OF ALKALI-RESISTANT CROPS.

The method of attacking the problem by cultivation consists of utilizing alkali soils by growing crops that are capable of enduring large quantities of salts. This would be the simplest method, provided crops could be found that would grow on all classes of alkali soils. Unfortunately, large areas of land contain so much alkali that not even the most resistant weeds or bushes can live. On such lands it is hopeless to attempt the cultivation of any crop until a portion of the alkali is removed. Certain saltbushes successfully withstand large quantities of alkali, and chemical examination of some varieties proves their value as forage crops. Their cultivation has been widely advocated by many writers on the subject. Saltbushes from Australia were introduced into California more than twenty years ago, but the most valuable species was not brought in until many years later. This is now commonly known as the Australian saltbush

(*Atriplex semibaccata*), and, on account of its rank growth and ability to resist drought as well as alkali, has been somewhat extensively cultivated in California, Arizona, and New Mexico. It may be used for pasturage or cut and cured as hay, yields of several tons per acre being not at all unusual. While this species does not thrive in the colder climate of the more northern States, native species do exist that give promise of success if cultivated. Speaking of the saltbushes of economic value in Wyoming, Nelson[a] says:

> Only the herbaceous species or those not woody are suitable for cultivation. Such are Nuttall's saltbush, Nelson's saltbush, and three annual species. Their cultivation would not be profitable on land where it is possible to grow forage plants which make a ranker growth and are more acceptable as feed to stock. Only on alkali lands unsuitable for other crops is it advisable to plant the saltbushes, and good yields will not be realized except on lands which are tolerably moist and which have been put in good condition of tilth.

While the cultivation of saltbushes has not perhaps been practiced long enough to make definite statements as to the future, sufficient trials have been made to prove that under certain conditions some revenue may be derived from land that would otherwise be nonproductive. By many it has been urged that the growing of such plants, which assimilate considerable quantities of salts, really becomes a means of freeing the soil of alkali. While it is true that such plants do take from the soil considerable alkali, the quantity absorbed by the plant as compared with the quantity remaining in the soil is very slight, so that years would be required to effect complete reclamation in case no other factors entered into the problem. This method, however, merely removes some alkali from the surface soil, while the rise of additional quantities from the subsoil is not prevented. On lands which will admit of other more profitable crops to be grown, sorghum ranks high as an alkali-resistant crop. At the Tulare substation the California experiment station reports sorghum growing luxuriantly in soils having a large amount of alkali, the surface often having a very dark incrustation from the black alkali. In the surface foot of soil chemical analysis revealed 0.872 per cent of total salts, a little more than half this quantity in the second foot, and slightly less quantities in the third and the fourth foot. The predominating salt was sulphate. From these results sorghum would seem to have a high tolerance for alkali salts and may be expected to grow where many other crops fail. Some varieties of barley and oats, as well as sugar beets, are also known as resistant crops. With these crops, however, when the quantity of total salts is as great as 0.60 per cent, difficulty is generally experienced in securing a stand. From these considerations it appears that for soils containing large quantities of alkali the crops capable of profitable cultivation are few in number at the present time, and that unless varieties are found that will withstand more alkali the use of alkali lands for crop production without reclamation is extremely circumscribed.

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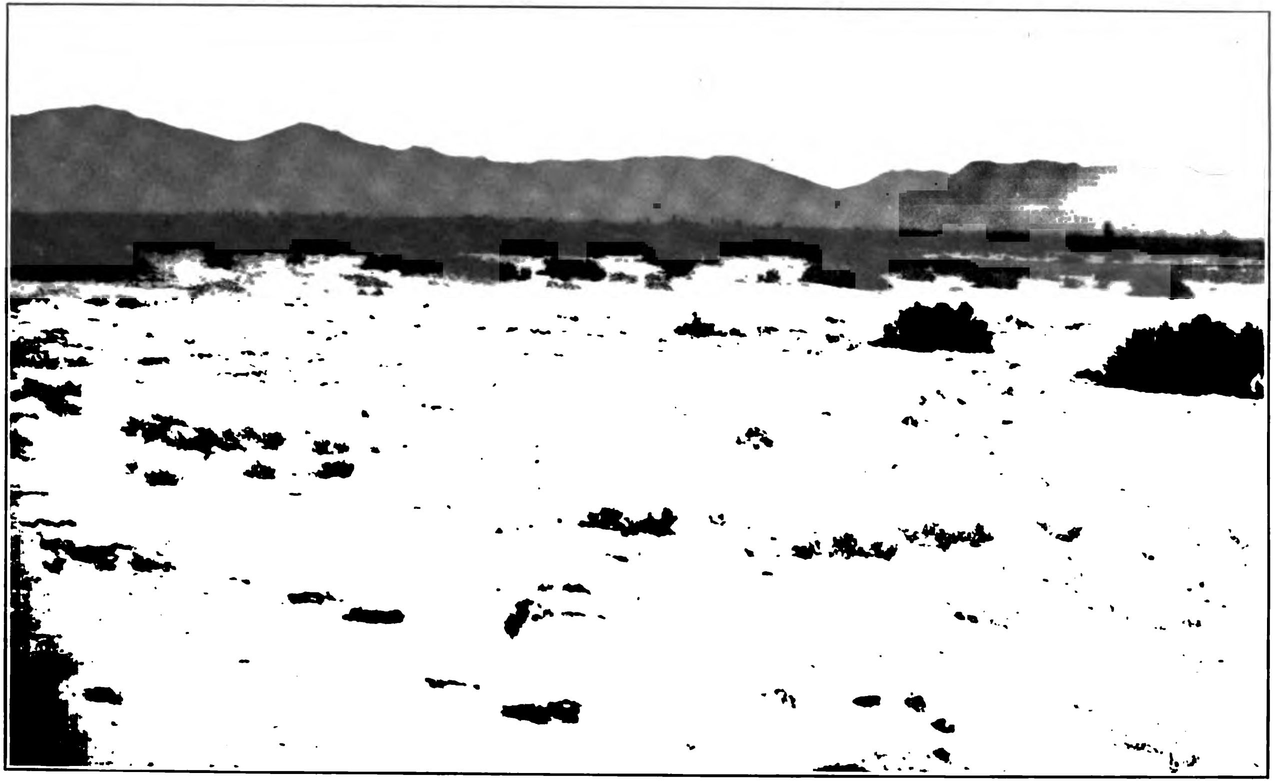
[a] Native and Introduced Salt Bushes, by Elias Nelson. Bul. No. 63, Wyoming Agr. Expt. Sta., 1904.

USE OF CHEMICAL ANTIDOTES TO RECLAIM ALKALI SOILS.

It has long been known that gypsum (calcium sulphate) exerts a beneficial action on soils containing black alkali, or sodium carbonate. It has not been found possible so far to add any substance that will neutralize white alkali, so the treatment of black-alkali soils alone need be considered. The application of gypsum to soil containing black alkali results in chemically changing the sodium carbonate or black alkali to sodium sulphate or white alkali. As compared with the carbonate the sulphate is quite harmless unless accumulated in much larger quantities. In addition to the chemical change attendant upon the use of gypsum the tilth of the soil is much improved. As a corrective for black-alkali soils, gypsum has been extensively used in California. In many cases when applied with sufficient water, it has been found possible to grow crops on land where previous attempts had resulted in failure. At the Tulare substation the California experiment station experimented for many years with the use of gypsum. Land was reclaimed to such an extent that crops could be grown, but in some places alkali came in from fields adjoining the experimental plot and more gypsum had to be applied.

With only small quantities of black alkali, and with the absence of other salts, beneficial results should follow the use of gypsum. In such cases the quantity of white alkali resulting from the chemically changed carbonate would be so small that it would not prevent the growth of crops. With a well-drained soil and conditions not favorable for a further increase of alkali in the soil the effects of this treatment should be permanent. On the other hand, if there is already considerable white as well as black alkali in the soil, the use of gypsum becomes more doubtful. With other forms of alkali present, the white alkali formed by the gypsum added to that already in the soil may often be sufficient to prevent crop growth. Again, it should be pointed out that while the black alkali may be changed to the less injurious sodium sulphate, conditions may again become favorable for the formation of more black alkali, necessitating the use of gypsum a second time. Moreover, there is the objection that gypsum does not remove the cause of the accumulation. Even considering these objections, there are undoubtedly many localities where the use of gypsum is to be recommended for soils containing small quantities of sodium carbonate.



ALKALI FLAT IN SALT LAKE VALLEY, UTAH.

The soil contains so much alkali that only the most resistant plants can live. No useful crops can be grown on such land.

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METHODS OF FREEING SOILS FROM ALKALI.

Any method that will remove accumulations of alkali from soils, whether these accumulations were formed by natural causes prior to irrigation or are the result of overirrigation on undrained soils, should receive careful consideration. Evidently the question of cost is of primary importance, since it will not pay to expend a greater sum of money to free the soil from alkali than the land is worth when reclaimed. Another vital point is whether the reclamation is permanent, for little real progress is made if land freed from alkali one year will accumulate sufficient alkali to prevent crop growth the following season. Some of the methods recommended and used more or less in different sections are: Scraping the surface; flushing alkali lands with water, then draining off the water; copious irrigation or flooding; flooding after the land has been artificially drained. Under favorable conditions any of these methods may be used and the soil put in condition for the cultivation of any crop suited to the soil and climatic conditions. So many factors enter into the successful treatment of alkali soil that every field, often every part of the field, should be studied before deciding on the course of action that should be followed. Because a certain method has reclaimed land in any particular area does not argue that it can be safely used in other places unless the same conditions prevail. Even then it may seem advisable to attack the problem in an altogether different manner. The causes of the alkali accumulation should be studied, also the amount and character of alkali. The vertical distribution of the alkali in the soil is important, and the character of the soil, whether it is sandy or clayey, impervious or readily permits water to move through it. Lastly, the depth to standing water should be carefully noted, as well as the position of the field or farm with reference to adjacent lands. It is only after due consideration has been given to all of these questions that we are in a position to recommend specific treatment for each individual tract of land. We may now briefly discuss the different methods that have been outlined above to determine under what conditions they are to be advised.

SCRAPING THE SURFACE.

At the close of a dry season much alkali can be removed by merely scraping lightly the surface of the soil. In case the greater part of the alkali is concentrated in the upper few inches of soil the quantity may be so reduced by scraping that crops can be started the following year. By shading the surface the growing crop restricts evaporation of the soil moisture, while subsequent surface irrigation tends to drive the remaining alkali downward, where it can do little if any harm. The success of this method of reclamation also requires that the water table be several feet from the surface. With these conditions this treatment may be the means of permanently freeing the soil of slight quantities of alkali and rendering it suitable for ordinary farm crops. While such a method is not generally to be recommended, since it does not remove the cause of the accumulation, it is apparent that under certain conditions it may be one method of eventually reclaiming alkali land at a very slight outlay of time and labor. Few if any instances of the successful use of this method have ever been recorded.

FLUSHING THE SURFACE.

Frequently an attempt is made to free the soil from alkali by turning water across a field, holding it on the land for a short time, and then draining it off. The principle involved is to allow the water to dissolve the salts in the upper part of the soil and on the surface, and then by immediately draining it off to carry the dissolved salts away. On sandy or porous soils with a shallow water table this method is very objectionable and increases the evil for which it is supposed to be a remedy. With the application of water to sandy soils the salts would at once be dissolved, but much of the water would sink into the porous soils and further raise the ground water, already so high that it is a fruitful source of alkali accumulation. The portion of water drawn off would undoubtedly carry some alkali, but this advantage would be negligible as compared with the resulting disadvantages. Yet under just such conditions flushing the surface is being resorted to in many districts by farmers who apparently do not realize the error they are committing.

The conditions favorable for this treatment are rather heavy or somewhat impervious soils, with the alkali largely concentrated at the surface and the water table several feet below. With these conditions the question of raising the ground water by the portion of water soaking into the impervious soil is relatively unimportant. The alkali, largely a surface deposit, will be dissolved and the greater part of the water will be drawn off with its dissolved salts. A few flushings may so reduce the quantity of alkali that crops can be started, and with the precautions of surface irrigation and restricting evaporation by shading the surface or by cultivation the land may be made productive. This method, although of somewhat limited application, may result in the permanent reclamation of alkali land.

FLOODING WITHOUT ARTIFICIAL DRAINAGE.

Certain definite conditions are necessary before this method can be recommended. The most essential points are that the soil be naturally well drained and the water table several feet below the surface. Under these circumstances the soil may be freed from even excessive quantities of alkali. After leveling the field sufficient water is added to cover the surface to a depth of several inches. By means of dikes or levees the water is held on the land and must of necessity soak through the soil, carrying with it the more readily dissolved salts. Repeated flooding finally leaches away the greater part of the alkali and enables the land to be cultivated. By care in handling such reclaimed land the chances for a second accumulation of salts are slight, provided that the ground water be kept sufficiently far below the surface. As much of the soil in the arid west is of a sandy nature, implying good drainage within the soil, the question remains just how deep must the ground water be to make reclamation by this method safe. This is a point that should be carefully considered, as well as the position of the field with reference to adjacent lands. Conditions may be such that with the ground water 3 feet or less below the surface the field may be entirely freed from alkali by this method. The alkali is leached below the surface and carried away with the country drainage where it works no injury to the soil being treated. With the ground water at this depth (3 feet), in case the reclamation of a large tract of land is attempted, the ground water would probably be raised above the danger point. So that while it might be possible to reclaim a tract of a few acres with a high water table, it would be a mistake to attempt the reclamation of a larger tract. Many cases have been observed where small tracts of alkali land have been completely reclaimed by flooding even where the water table was comparatively high. Likewise it should be mentioned that many failures have also been made by attempting reclamation under almost similar conditions. With the ground water 4 or 5 feet or more below the surface such attempts at reclamation are much more likely to succeed. The deeper the ground water the more readily will the water used in flooding leach the soluble salts into the deep subsoil, thereby diminishing the probability of their return to the surface. The success or failure of this method depends a great deal on choosing just the right time to start the crop. With the surface soil freed from alkali even to the depth of a few inches a piece of land may be entirely reclaimed. This enables the crop to start, and its growth effectually checks evaporation at the surface, while subsequent irrigation tends to reduce still further the alkali content of the soil. (See Pl. III.) Sorghum has frequently been recommended as a suitable crop to plant on land where the quantity of alkali is still considerable. This crop, as has been pointed out, is able to withstand not a little alkali, and at the same time admits of copious irrigation.

FLOODING COMBINED WITH ARTIFICIAL DRAINAGE.

When the ground water is high and cultivation is impossible as a result of seepage water and alkali, drainage must be resorted to before any real progress can be made. Even though the water table fluctuates greatly during the year recourse must be had to drainage, provided that at any time the water rises high enough to damage the deeper growth of crops or trees. A fluctuating water table, by submerging even for a few months the new feeding roots, may inflict as much injury as excess of alkali or a permanent high water table. Many cases have been observed where the loss of deep-rooted crops, orchards, and vineyards has been attributed to alkali when the sole cause of trouble was the extraordinary height of ground water at certain periods of the year. Some method of lowering the ground water at such time is as necessary as when the water table remains high throughout the year.

The method available for lowering a high water table or maintaining a fluctuating water table at a certain depth is some system of drains operated either by gravity or by pumping plants. The relative merits of the two systems must be decided after a careful consideration of the object to be accomplished. When the purpose to be gained is merely freeing an area of an excess of seepage water, thereby furnishing the initial step in the ultimate reclamation of the land, a system of gravity drains may be all that is needed. If, on the other hand, it is proposed not only to lower the water table, but also to develop additional water for irrigation, pumping plants may be necessary. In either case the question is purely an engineering problem and a competent engineer should be consulted before attempting operations on a large scale.

On small tracts of land with the ground water dangerously high and excessive quantities of alkali a system of gravity drains is perhaps the simplest method of attacking the problem. With such a drainage system in good working order the water table is permanently lowered to the depth of the drains. A ready outlet is provided through which not only seepage water from higher lands but the excess of water used in flooding or irrigation may carry away the harmful accumulations of salts leached out of the soil. Repeated flooding should eventually entirely free the soil from alkali, while the danger of future accumulations is greatly lessened by careful irrigation and precautions to prevent excessive surface evaporation. The principle of this method of reclaiming alkali land is exceedingly simple, but there are difficulties in carrying it out and many factors should be considered before attempting reclamation in any district. Inasmuch as the Bureau of Soils has been carrying on demonstration experiments by this method it seems advisable to describe somewhat briefly the progress of the work and results obtained at each reclamation tract.

RECLAMATION EXPERIMENTS OF THE BUREAU OF SOILS.

In 1899 the Bureau of Soils undertook the classification and mapping of soils in the United States. Methods for rapidly determining the quantity and character of alkali were devised and these methods used in the field. The origin and distribution of the alkali were studied, as well as the various quantities of the different kinds of alkali sufficient to prevent the successful growth of crops cultivated in each area. Carefully prepared maps were also made showing the exact amount and distribution of alkali in each area. In addition recommendations for handling such lands were made in the reports describing the results of the work. It was emphasized that by providing suitable drainage the soluble alkali could be leached from the soil by repeated irrigation and the soil restored to its original fertile condition. As years passed by with no effort on the part of those interested to undertake such methods of relief the Bureau became convinced of the advisability of taking up reclamation work as the best means to prove the force of its recommendations. Accordingly a number of locations were selected in which such demonstration work should be undertaken.

In the summer of 1902 work was begun near Salt Lake City, Utah; in the winter of 1902 a second tract was selected at Fresno, Cal.; in 1903 a third tract was chosen at North Yakima, Wash. During 1904 reclamation experiments were started at Tempe, Ariz., and at Billings, Mont. At each of these stations the soil conditions and the character of the alkali differ. At each tract selected a drainage system of ordinary draintile was installed to a depth of 3 or 4 feet, the land leveled and divided into checks or plats by levees, so that it could be flooded, and ample provision was made for the removal of the drainage water. Careful tests were made to determine the amount and character of alkali present and arrangements were made to measure the water applied in flooding, as well as the quantity carried off by the drainage system. Tests were also made to determine the amount of alkali removed by the drainage water.

At Salt Lake City, Utah, a tract of 40 acres was selected and the work was carried on in cooperation with the Utah experiment station. The tract is situated about 4 miles west of the city and in its original condition supported only a sparse growth of the alkali-resistant greasewood and salt grass. Nearly the whole 40 acres was heavily incrusted with alkali deposits and the appearance of the tract was about as unpromising as one could well imagine. No attempt had ever been made to cultivate the land, but a railroad embankment crossed it and streets had been graded upon it. The soil consists of a heavy silty loam with a clay subsoil. Tests showed the quantity of alkali to a depth of 4 feet to average from 2½ to 5 per cent, mainly sodium chloride or common salt, or more than five times as much as ordinary crops will tolerate.

The drainage system was installed late in the summer of 1902. This consisted of lines of draintile 150 feet apart at an average depth of 4 feet. During 1903 systematic flooding was carried on from May to October. Tests at the close of the season showed that by far the greater part of the alkali had been leached from the soil. In the spring of 1904 the entire 40 acres was planted to wheat, oats, and barley. On account of late seeding the stand was not the most promising, but was ample to show that the upper foot or more of soil had been practically reclaimed. Flooding was carried on for about six weeks in 1904. Crop tests in 1905 gave better results. At present (March, 1906) 13 acres are in alfalfa with a good stand; 4 acres are in winter wheat, while alfalfa and other crops will be planted on the remainder of the tract.

A second tract of 20 acres was selected 4 miles south of Fresno, Cal., and a drainage system installed during the winter of 1902. This tract of land was at one time considered some of the finest fruit and vineyard land in the Fresno district. At the time irrigation was first commenced in this region the water table was in the neighborhood of 80 feet below the surface. By using excessive amounts of water and by the enormous loss from the canals running through the sandy soils of the country the entire region became filled with seepage water until at the present time the water table in some sections rises to within 1 foot of the surface. Attendant upon the rise of the ground water came the bad effects due to the accumulation of alkali, and for miles in this part of the Fresno district former fine vineyards and orchards are now abandoned or valued only for their scanty pasturage. In the Fresno tract no outlet was available for the drainage water, except by installing a water-wheel pump upon one of the irrigating canals and lifting the drainage water from a deep sump dug for this purpose. The soil of the tract is known as "white ash land" and is a fine sandy loam which contains considerable volcanic ash. The alkali on this tract consisted largely of sodium carbonate, or the dreaded "black alkali."

Flooding was carried on during the year 1903 and by far the greater part of the alkali removed. In 1904 crop tests on those portions of the land considered more fully reclaimed were valued at $230. (See Pl. IV.) Flooding was considered necessary on some portions of the tract which still showed the presence of alkali. Late in the fall of 1904 the greater part of the tract was seeded to alfalfa, and in the early spring of the past year this had made a fine growth and the appearance of the entire tract was favorably commented upon by all those who had watched the course of the experiment. The crop returns for 1905 were approximately $300.

Early in the summer of 1903 the Bureau selected a tract of 20 acres for a demonstration experiment at North Yakima, Wash. This tract of land is situated about 3 miles south of the town, and at the time of the selection was covered with a heavy growth of greasewood and salt grass. It is situated along Wide Hollow Creek, in a section where many fine farms have been ruined by the accumulation of seepage water and black alkali. The soil is a fine sandy loam characteristic of the volcanic ash soils of the Yakima Valley. Flooding was carried on during a portion of 1903 and again in 1904. Late in the fall of 1904 wheat was sown on the entire tract. This made a fine start, but by the spring of 1905 there were some spots that showed the presence of alkali in sufficient quantities to prevent the growth of a good crop. More than half the tract, however, produced a heavy growth of wheat, which reached in some cases a height of 6 feet. This was cut green for hay and produced a crop valued at $160. Flooding was carried on during the past season, as it was evident that some places still remained where there was a considerable quantity of alkali. During the past fall the land was prepared and seeded to alfalfa, with wheat as a nurse crop. While it is yet too early to predict the outcome for this tract there will probably be some small places that will require further attention, as it seems to be very difficult to leach all the black alkali from soils of this character.

Early in 1904 another tract was located near Tempe, Ariz., in the Salt River Valley. During the year 1904 water was available only for flooding purposes a few months of the entire year. By far the greater amount of alkali, however, was leached from the soil during these months and test crops were started. The winter of 1905 was a remarkable one in this valley on account of the very heavy precipitation, and though the crops had made a fine start they were badly damaged by the very heavy rainfall. At the present time the alkali has been practically all leached from the soil and the greater part of the tract is seeded to alfalfa and barley, which give promise of a fine stand.

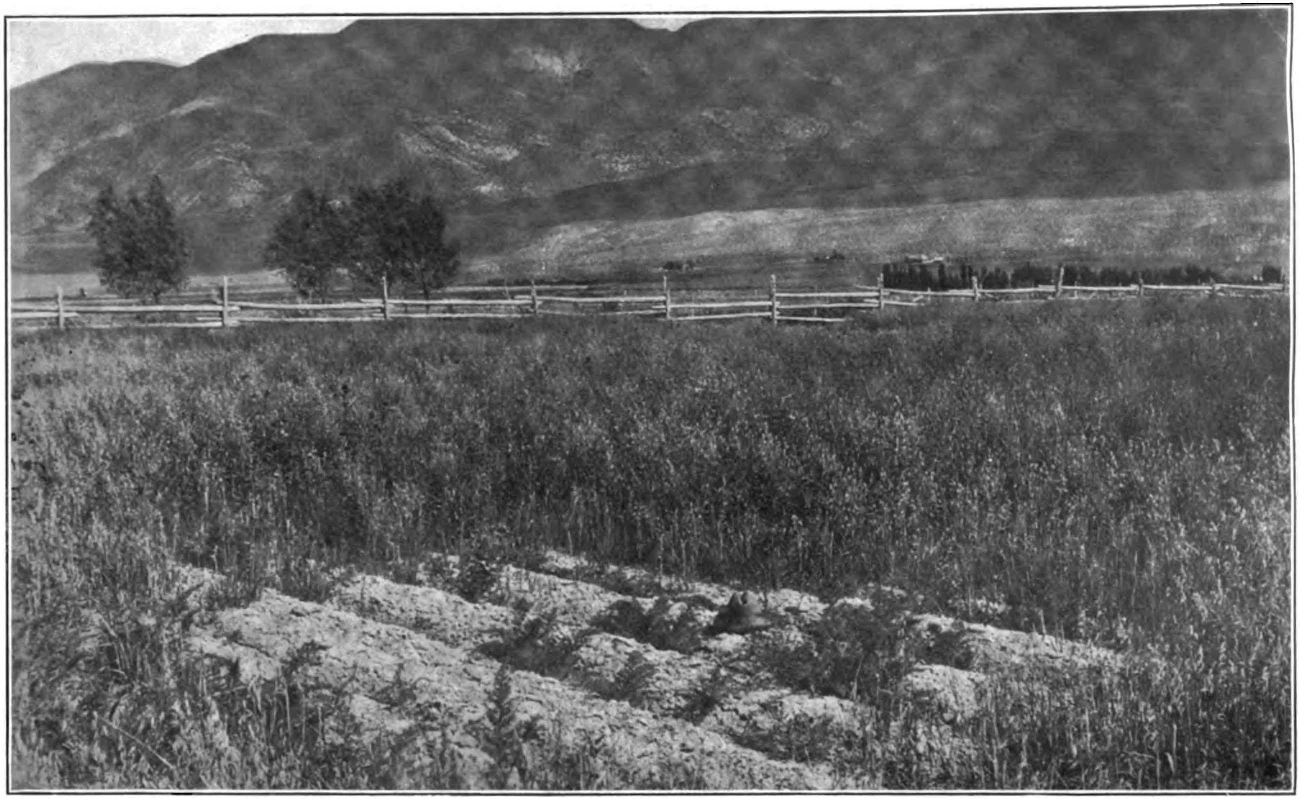
During the same year a fifth tract was installed at Billings, Mont., in the Yellowstone Valley. Alkali has increased very rapidly in this valley until at the present time it is a serious factor in the successful cultivation of much of the irrigated land. A tract of 20 acres about one-half mile west of the town of Billings was selected for demonstration. One or two unsuccessful attempts were made to cultivate the land of this tract about twenty years ago. Since that time no further attempts have been made to produce crops upon it. When selected by the Bureau it was covered with a meager growth of greasewood and salt grass, while heavy incrustations of alkali covered a large portion of the field. Much of the soil consists of a heavy adobelike soil characteristic of the valley and locally known as "gumbo." The alkali in this valley is somewhat unique, inasmuch as it consists almost entirely of sodium sulphate. The installation of the drainage system was completed too late to allow any flooding operations to be carried on during 1904, but during the past year the entire tract was kept submerged for a period of several months. In addition to this, heavy rains during the early spring months of 1905 greatly assisted in leaching the alkali from the soil. Tests made during the summer of 1904 showed more than 1 per cent of alkali present in the soil to a depth of 4 feet, by far the greater amount occurring in the surface foot of soil. Tests made in the fall of 1905 showed that nearly all of the alkali had been leached from the first and second foot and comparatively small quantities remained in the third and fourth foot. A test crop will be sown as early as weather conditions will permit to make a practical determination of the extent to which reclamation has actually progressed.

EXPERIENCE GAINED FROM DEMONSTRATION EXPERIMENTS.

From the results on these five tracts it is seen that by carefully leveling the surface and by installing an adequate underdrainage system systematic flooding for one year is able to remove by far the greater proportion of soluble salts from soils containing even excessive quantities. As has been mentioned, the underlying principles of this method of alkali reclamation are simple enough, but there are certain difficulties in carrying the work to completion. In order to facilitate the work, it will be found advisable thoroughly to level the land before beginning operations. High spots that can only with difficulty be covered with water tend to hold and accumulate alkali, as already explained.

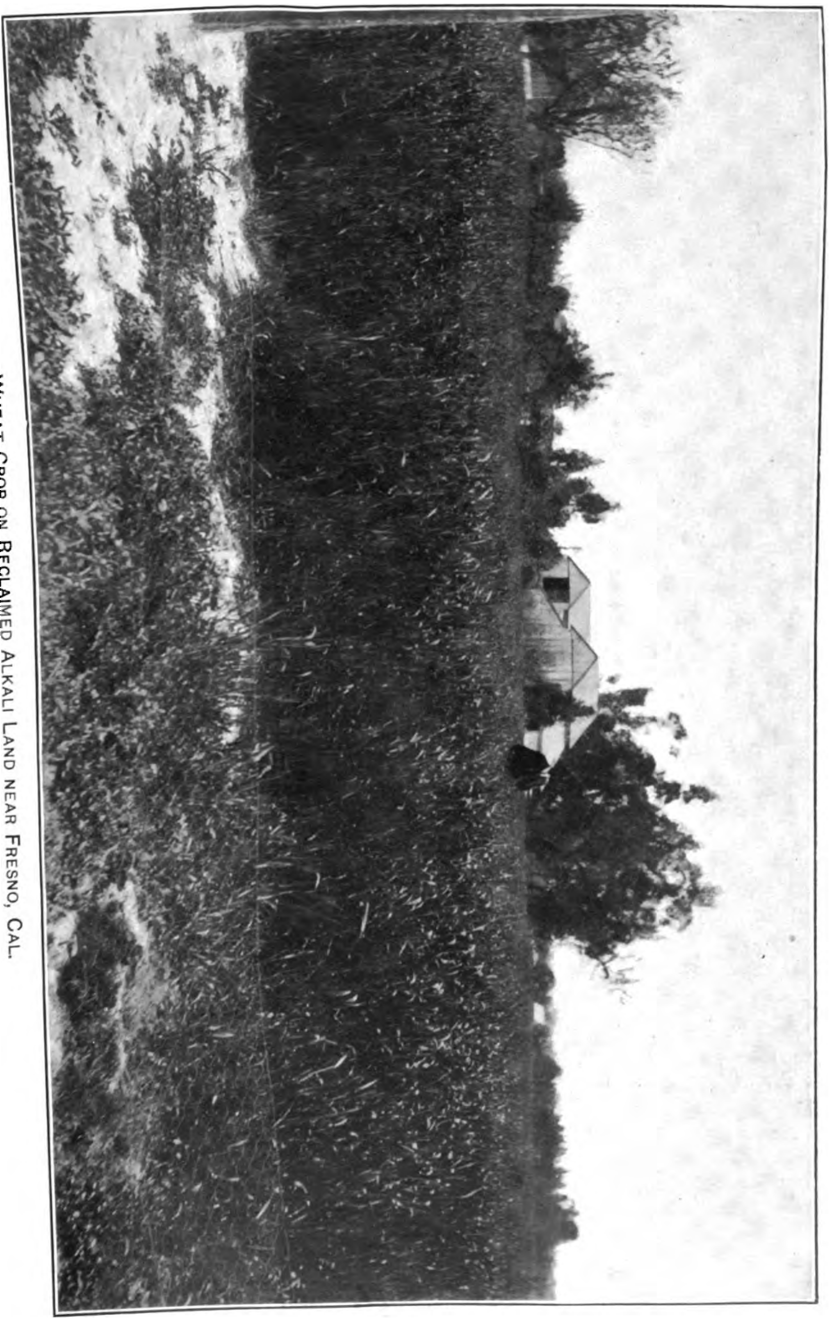
To provide an adequate drainage system, while the first essential step, will not of itself reclaim soils containing excessive quantities of alkali. The installation of a drainage system may effectually check the further accumulation of alkali, but it is only when abundant supplies of water are added that the soluble salts are leached downward through the soils and carried away by the drains. During the progress of flooding the tilth of the soil will perhaps be destroyed, the soil may become water-logged, and other bad results may follow. This will be especially the case if the soil is of such a character at to be easily damaged by repeated flooding.

At Salt Lake City, Utah, and at Tempe, Ariz., it was found that the soil in places plainly showed the effects of flooding. At the former station the soil is a silty loam that must be handled carefully at all times. It has a tendency to bake, forming a hard crust. In 1904, when the first crop test was made, most of the grain sprouted nicely, but examination showed the young seedlings curled and doubled, unable to break through the hard, baked surface. The first crop was not harvested, but plowed under to improve the tilth of the soil. At



SMALL ALKALI SPOT REMAINING IN A FIELD RECLAIMED BY IRRIGATION IN THE SEVIER VALLEY, UTAH.

Before reclamation no cultivated crop could be grown.



WHEAT CROP ON RECLAIMED ALKALI LAND NEAR FRESNO, CAL.

Reclamation has been accomplished in one year by flooding combined with underdrainage.

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Tempe, also, it was deemed advisable to apply manure to those places where the soil had been put in bad physical condition. In many cases, especially with heavy soils, cultivation and turning under the first crops will often be necessary to restore the soil to a good state of tilth.

POSSIBLE INJURY TO THE LAND BY CONSTANT FLOODING.

Some have urged that flooding not only water-logs the soil and destroys the tilth, but also washes away the supplies of available mineral plant food. It is true that other mineral salts besides those injurious to crops may be leached from the soil, but the store of plant food in about all classes of soils is so great that no fear need be entertained that as soon as the alkali content is leached away the crop will suffer for lack of sufficient mineral nourishment. The mineral constituents entering into the composition of the crop are largely absorbed by the soil grains, and while the more readily soluble portion of these constituents might be leached away the soil would soon readjust itself, so that it would furnish all the essential mineral ingredients needed by the growing crops. Reclaimed alkali soils put in good condition as regards tilth and ventilation will be found as productive as those on which no flooding is necessary.

On certain soils it is a difficult matter to hold the water on the land, especially if the land has considerable fall. This has been found to be the case at North Yakima, Wash. On this tract the fall is approximately 1 foot in 100 feet, and with the light ashy soils derived from volcanic débris the dikes or levees surrounding the small plots of land have repeatedly broken during flooding operations. Banks 2½ feet high and 3 feet wide at the base, when water was turned against them, at first acted almost like so many piles of sugar or salt. Even after they have been tamped and saturated many times the banks must be carefully watched to guard against breaking. Some farmers in the Yakima Valley who have attempted to hold water on their soils have given up in despair after a few disastrous breaks, which caused deep trenches to be cut across the fields they were flooding. By patrolling the banks the danger from these breaks is lessened, but this question must be considered in any attempt at reclaiming sloping fields with the light, porous volcanic ash soils found in the Northwest.

EFFECT OF HARDPAN ON ALKALI RECLAMATION.

An obstacle seriously retarding reclamation by any method that involves leaching the alkali downward is the presence of hardpan. Bands of more or less firmly cemented hardpan occur in almost all arid soils and have been frequently likened to the clay subsoils usually found in countries of abundant rainfall. Hardpan in many instances consists of a thin layer of sandy, gravelly material cemented together by calcium carbonate, iron compounds, or other cementing substances. Oftentimes upon the application of water this softens and no longer offers any resistance to the ready downward percolation of water. This is especially the case with a calcareous hardpan. The ferruginous hardpan softens little, if any, upon coming in contact with water. In some districts calcareous hardpan may extend a foot from the surface to a depth of several feet, forming a firm, continuous mass approaching in character a somewhat thick bed of limestone, so compact that it can only be broken by picks or heavy iron digging bars. Such layers or sheets of hardpan not only retard the percolation of water, but also greatly hinder the growth of deep-rooted crops and trees of all kinds.

In areas where such beds of hardpan occur it is to be doubted if it is advisable even to attempt to reclaim alkali soils. With the hardpan a foot or two from the surface the alkali can be leached to this depth, but probably no farther, on account of the slowness with which the water moves downward through the layers of hardpan. With the alkali at this slight depth, under favorable conditions it will rise slowly or rapidly to the surface, depending on the rate of evaporation of the soil moisture. Just such difficulties have been experienced on small spots in the reclamation tract near Fresno, Cal. Certain portions of the tract are underlain at a shallow depth by formidable beds of compact hardpan. The soil overlying this hardpan was freed from alkali by flooding, so that crops could be grown, but subsequent examination showed the alkali lodged in the upper layers of hardpan. Cultivation and cropping of the reclaimed soil above the hardpan prevented the rise of the alkali, but such treatment was necessary to prevent it from again accumulating at or near the surface. Breaking the hardpan at frequent intervals or open ditches instead of covered drain tiles would probably assist in allowing the water to penetrate more freely through this obstruction and consequently accelerate the final reclamation of lands with layers of hardpan a few inches in thickness. When the hardpan is within a foot of the surface and several feet thick, freeing the soil of alkali by leaching becomes of more doubtful application, if indeed it can succeed at all.

In this same connection it seems advisable to speak of the absorption of soils. Certain soils, especially clay soils, have a high absorption capacity for all kinds of soluble mineral matter. On such soils the first few floodings will leach away the excess of alkali salts, but beyond a certain point flooding will accomplish little toward removing the remainder, which is tenaciously held by the soil grains. In case of black alkali the portion absorbed and held by the soil may be sufficient to prevent the growth of crops. Just how far this factor enters into the successful reclamation of black-alkali soils is now being investigated in the laboratories of the Bureau of soils.

In reclaiming small tracts of alkali land in the midst of districts where the seepage waters move rapidly through the porous sandy soils, adequate provision must be made for the removal of the great quantities of water pouring in from all sides. If the drainage of the entire district were provided for, it becomes comparatively simple to install a drainage system that will remove the water necessary to leach away the alkali salts. If no regional drainage has been undertaken, the drainage system must be of such capacity as to carry away not only the excess of water applied at the surface and leaching downward through the soil, but that quantity that infiltrates from adjacent fields surrounding the particular tract of land being treated. At Fresno the Bureau has found it advisable to considerably enlarge the original drainage system for this very reason. The tract is located in a district where at certain months the ground water rises to within a few feet of the surface. To prevent the ground water from rising above a height of 3 or 4 feet it was necessary to lay lines of tile of larger dimensions and increase the water-wheel pump to three times its former capacity.

CLOGGING OF THE DRAINS.

The question of keeping the tiles free from silt and roots must be considered if the drainage system consists of drain tiles. Since drain tiles have been proved by many years of experience to be the most economical drainage implement, their use is to be recommended. Open drains are equally effective, and in Egypt large areas of alkali land have been reclaimed by surface flooding and drainage systems consisting of open ditches. Open ditches are cheaper, equally effective, and in districts where drain-tiles are to be had only at exorbitant prices may be used to good advantage instead of tiles or box or board drains. In sandy soils that do not stand well in bank open ditches will take up much valuable space and must be frequently cleaned to be effective. For a drainage system of tiles to be effective, the tiles must be kept free from all obstruction, such as roots and sand or silt. Some soils, especially those that carry large quantities of fine micaceous silt, enter through the joints of the tiles almost as readily as water. Heavy clay soils when firmly settled over the lines of tile cause little trouble, and the tiles have to be cleaned only at long intervals or not at all. At Fresno, Cal., the Bureau has had difficulty in keeping the tiles open and effective at all times. In the newly installed drainage system at that point steel-wire cables have been placed in all tiles. To these cables wire brushes may be attached and drawn through as often as the occasion demands. On two large ranches in the Fresno district the same difficulty has been experienced. It is now several years since the drainage systems were installed, and it is still necessary to draw wire brushes through the tiles twice each year to free them from silt and roots. By this method the systems have been kept in perfect order, and the ground water is maintained at the level of the tiles. Where it is believed no especial trouble need be feared from silt, in extra long lines of tile, occasional silt boxes may be sunk below the level of the tiles. These serve as a check on the manner in which the tiles are working and can be cleaned as often as required. They may also be used to serve as standpipes to introduce water under pressure into lines of tile that may become clogged by local obstructions. They can be cheaply placed in position at the time of installing the drainage system.

DEPTH AND DISTANCE APART FOR DRAINS.

In considering the depth of the drainage system it should be remembered that the deeper the drains the greater the depth of alkali-free soil obtained after the land is reclaimed. This is important, as is also the depth to the water table, which is also lowered by the drainage system. These factors should be taken into consideration, always keeping in mind the increased cost of placing the drains at greater depth. For each foot of earth removed the cost of digging ditches greatly increases, so that beyond certain depths the question resolves itself into whether the farmer can afford the extra cost. With cheap labor it will be found more economical to make a few deep ditches than many shallow ones. The deep ditches not only lower the water table to a greater depth, but also drain a wider area of soil, hence fewer drains are needed. With deep drains the chances for future rise of alkali are reduced. In certain classes of soils capillary action lifts water from a depth of several feet. Obviously if the depth of reclaimed soil is considerable, and even below the depth from which capillary water will rise, there will be practically no danger from a further accumulation of the alkali washed down to the level of the drains. In most cases it will be difficult to install a drainage system below this depth, but each additional foot of reclaimed soil makes a second alkali accumulation more improbable. In practice it is not advisable to place drains less than 3 feet deep, and depths of 4 or 5 feet or more give much better results.

The distance apart at which drains should be placed depends largely on the character of the soil. In heavy soils rapid reclamation may be accomplished with drains 100 to 150 feet apart. In porous sandy soils the distance may be greater, intervals of 250 to 300 feet in many cases answering the purpose. The less the interval between drains the more rapid can reclamation be carried on, but the distances given above are conservative.

COST OF RECLAIMING LANDS BY FLOODING AND DRAINAGE.

As to the cost of carrying on such reclamation, it has been found to depend on the local conditions in each area. While in the central portion of the United States all sizes of drain tile are sold at reasonable prices, this is not the case in the West. Factories making such material are few and inclined to sell their product at a little less than such material could be shipped from eastern points. At the present time such prices are almost prohibitive. The demand for drain tile has been so limited that there is, as a matter of fact, very little inducement for people to engage in this business, and the farmer undertaking the drainage of his land is at the mercy of the few established manufactories. Even considering the exorbitant prices at which the farmer must purchase his tile, it is still possible in the greater number of western districts to provide an adequate drainage system for small tracts of land at an average cost of from $15 to $25 an acre. Drains consisting of boards are also effective, but they are not so permanent as drain tile and in many localities will be found nearly as expensive in the first instance.

To reclaim lands containing any considerable amount of alkali will cost from $30 to $50 an acre, including the cost of installing drains, leveling the land, and constructing necessary levees and dikes, as well as the cost of flooding. The item of leveling has been estimated at from $5 to $15, which would cheapen the cost of reclamation just so much in case the land had previously been leveled.

This method of reclamation has been used successfully in Egypt, as well as at many places in the United States, and, with the possible exception of areas underlain with hardpan, there can be no doubt of its feasibility in the irrigated districts of this or any other country.

CONCLUSION.

In the foregoing pages it has been shown that arid soils are rich in water-soluble mineral matter. In small quantities these mineral salts are probably beneficial to plants, but excessive quantities prevent the growth of valuable crops. Alkali salts move within soils only in the presence of water or soil moisture, and injurious accumulations are usually the result of overirrigation or seepage from canals, with no provision for removing the water in excess of that needed by growing crops. Certain precautions greatly retard, if not altogether eliminate, injurious accumulations of alkali, but for areas already ruined by alkali salts the problem becomes more serious. Several methods are available for removing or counteracting the alkali. Each method under certain conditions can be relied upon to give satisfactory results, but the landowner should carefully study all phases of the question before deciding which method is best adapted to his needs. He should determine the value of his land in its present condition and its producing value, as well as market value when once reclaimed. It is poor business judgment to expend more money and labor to reclaim land than the same land will be worth after it is reclaimed. It is likewise short-sighted policy to abandon valuable land that can again be made productive by the expenditure of small sums of money or by the farmer's own well-directed efforts.

As the need of drainage is more thoroughly appreciated, measures will be enacted that will bring relief to districts suffering from seepage waters and alkali. In speaking of alkali in Colorado, Dr. W. P. Headden, of the Colorado agricultural experiment station, states that "the only question of alkali that we have resolves itself into one of drainage, and beyond this there is no alkali question." This need of drainage is becoming more imperative as conditions grow worse, and in some districts each succeeding year marks a step forward in this direction. Sentiment is being aroused on all sides and the formation of drainage districts controlled by just laws is under way in a few irrigation centers. With the drainage of those districts badly damaged by seepage and alkali provided for, the control of alkali becomes a problem easy of solution. Until such time real progress can be made only by the individual efforts of farmers or groups of farmers.

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U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF SOILS—BULLETIN No. 35.

MILTON WHITNEY, Chief.

ALKALI SOILS OF THE UNITED STATES.

A REVIEW OF LITERATURE AND SUMMARY OF PRESENT INFORMATION.

BY

CLARENCE W. DORSEY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1906.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., May 24, 1906.

SIR: I have the honor to transmit a manuscript entitled Alkali Soils of the United States—A Review of Literature and Summary of Present Information, prepared by Clarence W. Dorsey, of this Bureau. I recommend the publication of this compilation as Bulletin No. 35 of the Bureau of Soils.

Respectfully,

MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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ALKALI SOILS OF THE UNITED STATES—A REVIEW OF LITERATURE AND SUMMARY OF PRESENT INFORMATION.

ALKALI CONTENT OF ARID SOILS.

The climate of arid regions is directly responsible for the prevalence of sandy soils containing large stores of water-soluble materials, which at once become productive upon the application of water. Even the most desolate stretches of desert will supply good crops if the needed water is applied, as is shown by the millions of acres of land now under cultivation that were formerly a barren desert. While this is generally the case there are a few exceptions, one of the most striking of which is when the soil contains alkali. Frequently alkali[a] does not appear in an irrigated district until cultivation has been practiced for a number of years. The substances composing the alkali may be present in the soil before the application of water, or they may be brought in by the irrigation waters. In hot, dry weather, after rains or irrigation, the alkali frequently appears on the surface of the soil as a white crust.

Generally speaking, in most irrigated districts water is used in excessive amounts. Usually the farmer, seeing the benefits derived from irrigation, overirrigates his land, with the consequent damage arising from the accumulation of alkali salts and seepage waters. The accumulation of seepage water, either in pools or in sloughs, or filling the soil spaces of low-lying, poorly drained lands, is caused either by leakage through the sides and bottoms of the canals and laterals, or by excessive irrigation of higher-lying lands. Water in excess of the amount required by growing crops percolates downward, fills the soil, and finds its way through the more porous substrata to lower levels and local drainage basins.

As a result, we find few irrigated districts entirely free from the troublesome alkali after irrigation has been practiced a few years. Little provision is made for the drainage of lands when irrigating canals are built, as the country is then suffering from a lack of water. Traces of alkali may be noticed in places on the surface of the ground, or some of the characteristic alkali weeds may tell the experienced rancher that future difficulty may occur from the rise of alkali. Usually the amount of strongly impregnated alkali land is so small that little attention is paid to it, and as the ground water is many feet below the surface the need of drainage channels is not apparent. After a few years of excessive irrigation the water table rises. Capillary action pumps the water to the surface of the soil, where it evaporates, leaving the dissolved salts on the surface, where they accumulate to the detriment of the growing crop. Soon deep-rooted crops, such as alfalfa, begin to suffer from the rise of ground water, until they are completely swamped, while the areas of heavily incrusted alkali soils grow appreciably larger each year. Occasionally a single season suffices to transform a flourishing alfalfa field into a barren alkali flat. This is not the experience of a single irrigated district, but the common experience in all irrigated countries of little rainfall.

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[a] The term "alkali," as used in this bulletin, refers to water-soluble mineral salts which exert a harmful influence on vegetation if accumulated in sufficient quantity, and has no reference to the term as used by chemists. Chemically considered, the various kinds of alkali of arid regions are salts.

Thus it is seen that one of the drawbacks to irrigation farming is the liability to damage resulting from the rise of alkali and seepage waters unless reasonable precautions are taken. If provision were made for carrying away the surplus of water when the irrigation canals are built, the trouble from these sources would be reduced to a minimum. By using as little water as possible, with frequent cultivation of those crops that leave the soil partly uncovered, the danger from accumulations of alkali is lessened. Cultivation materially checks surface evaporation, while the restricted use of water reduces the chances of the deep subsoil becoming saturated so soon after irrigation is commenced. Unfortunately, however, few such provisions are made, and the alkali question becomes more serious from year to year. Even in districts suffering most from this cause little effort is made to check the spread of alkali. Often through lack of knowledge of how to fight the evil or from disinclination to combat it the farmer abandons his land. In many districts, what were formerly the choicest tracts of land are now alkali flats or salt-grass pastures. In some districts land values have depreciated from several hundred dollars an acre to a merely nominal value. Conservative estimates show that about 10 per cent of the irrigated land in the arid regions of the United States contains so much alkali as to be practically unfit for cultivation to any but the most alkali-resistant crops. In 1902 the United States Census Bureau gave the amount of irrigated land in the arid States and Territories as 8,471,641 acres. Ten per cent of this is, approximately, 847,000 acres. Placing a valuation of $50 per acre on this land, a very conservative estimate, we find that the West has lost lands valued at more than $42,000,000 on account of alkali. This shows the enormous damage already caused, and the evil increases from year to year.

COMPARISON OF SOILS OF ARID AND HUMID REGIONS.

The question naturally arises why arid soils alone should suffer from alkali. This is easily answered when we study the origin and formation of soils in different parts of the country. One of the most striking characteristics of the soils of arid or semiarid regions is the large amount of water-soluble material contained in them. This is in decided contrast to the soils of those regions where copious rains occur the greater part of the year. Soils consist of more or less finely divided rock fragments which have been acted upon to some extent at least by the weathering influences of climatic agencies. Of the agents that operate to transform the various kinds of rocks into soils we find that water is one of the most powerful. Running water, with its enormous transporting and abrasive capacities, is a potent agent in forming soils by mere mechanical processes. Freezing water, by disrupting or tearing asunder rock masses, is another important factor in soil formation. Rain water is a great solvent and acts upon rocks to change them into soils, dissolving out their component parts. As rain water is never found pure, but always carries carbon dioxide, which increases its solvent power, it leaches out the most easily dissolved substances and carries them away. Chemical examination of the waters of springs, lakes, rivers, and the ocean shows them to contain variable amounts of saline material which have been dissolved from rocks. Other agents, such as changes of temperature, wind action, the effect of small forms of animal and vegetable life, as well as many chemical actions, also hasten the process of reducing rock masses to soils capable of supporting vegetation.

The influence of the forces tending to form soils varies greatly in different parts of the world, depending largely upon the climatic conditions. Rock decomposition advances more rapidly and completely in tropical countries receiving an abundance of warm rain, while in elevated plateaus with little or no rainfall the formation of soils takes place more slowly. In the first case the most insoluble parts of the parent rocks predominate in the resulting soils, while in the arid countries the soils are merely broken rock fragments that frequently have almost the same chemical composition as the original rocks.

Thus we find that in the arid and semiarid countries the composition of the soil is quite different from that of the humid countries receiving rainfall sufficient to grow crops without irrigation. The soils of the dry desert countries are rich in salts that yield the mineral nutrients for plants, while to a large extent these minerals have been leached out of the soils in those regions receiving abundant rainfall. Analyses show that the soils of arid regions contain many times as much magnesium and lime as the soils of humid regions. As the content of lime in the soil is frequently indicative of its productive capacity, the large amount of this material found in arid soils is a strong point in their favor and is verified by their wonderful fertility when irrigation water is supplied. Again, the amount of potash and soda found in the soils of arid countries is largely in excess of that contained in soils where rainfall is abundant. In the case of phosphoric acid, another very important soil ingredient, there is little difference between the amount contained in the soils of humid and arid regions. The amount of humus found in arid soils is quite low. Sandy or light-textured soils are the rule in regions of little rainfall, but they are very retentive of moisture—far more so than the soils of similar texture in humid countries.

ORIGIN OF ALKALI.

The origin of alkali is, in general, uncertain, although it has been the subject of much speculation, and a number of hypotheses concerning it have been advanced. These hypotheses are, as a rule, open to serious objections, and brief mention only of the more prominent ones will be given.

In a few cases the genesis of alkali can be clearly traced. For instance, in the Billings area, Montana, where the alkali is almost entirely a mixture of sulphates of sodium with lesser amounts of magnesium sulphate, it seems obvious that the source of the material is found in the sulphides of iron prevalent in the Fort Benton shales, which on exposure to the air oxydize to the sulphates and then on contact with water hydrolize, forming sulphuric acid and ultimately the sulphates of the alkalies and alkaline earths. In other cases deep-seated springs, yielding water carrying salts or even free mineral acids, such as hydrochloric or sulphuric acids, can be regarded with much probability as the origin of the alkali. But such cases are usually sporadic and of relatively unimportant extent.

In by far the greater number of cases throughout the world where alkali or similar accumulations of soluble salts occur, the predominating salt is sodium chloride, with lesser amounts of other chlorides, sulphates, and sometimes carbonates. Occasionally other salts are present, but rarely in significant amounts.

This mixture of salts, resembling so closely that contained in sea water, naturally suggests the latter as the origin. In some cases it may be regarded as fairly evident that the salts do come from more or less deep-seated deposits resulting from the desiccation at more or less remote periods of time of bodies of sea water. In many cases, however, there is a total lack of confirmatory geologic evidence, and this explanation must be regarded as very unsatisfactory.

It has been suggested that some of these deposits may be the result of wind-blown spray from pelagic sources. The enormous distance to which it is known that dust is sometimes carried to sea lends probability to this hypothesis. But it is difficult to see how such wind-blown masses could pass high mountain ranges without precipitation, and it is even more difficult to see why there should be the excessive precipitations in any one area which would be necessary to account for the large masses of salts in these accumulations.

Another hypothesis has been suggested by Dr. Frank K. Cameron, of this Bureau, which has the merit of having a wide general application and seems to be in entire accord with well-known soil phenomena. As it has not, so far as we are aware, been advanced hitherto, it is given here in some detail.

The major part of the complex crystalline masses or rocks forming the earth's crust contain chlorine and sulphur. F. W. Clark[a] gives as an average 0.07 per cent chlorine and 0.108 per cent sulphur. As a result of the hydrolizing action of water[b] and other decomposing agencies, probably all the chlorine and very much of the sulphur is converted into hydrochloric acid and sulphuric acid, which in turn form the corresponding salts of the alkalies and alkaline earths. The aggregate amount which is thus being constantly formed in the subsoils and underlying strata of any one area must be very large. As evaporation proceeds at or in the surface soil, there is a rise of the water in the underlying layers through the capillary spaces toward the surface, bringing with it the hydrochloric and sulphuric acids or their salts.

The sulphuric acid moves up more slowly than does the hydrochloric acid, partly, perhaps, because the rock masses and the soils have a greater absorbing action on sulphuric than on hydrochloric acid, tending to withdraw it from solution; partly, perhaps, because reducing conditions may exist in some layers tending to the formation of metallic sulphides, and partly, undoubtedly, to the formation of the slightly soluble calcium sulphate. This last, however, is gradually brought toward the surface, and is often found in enormous masses at slight depths in the soils of arid regions. Undoubtedly the calcium carbonate so generally found in large masses at moderate depths in the soil of arid regions originates in a similar manner.

Hydrochloric acid is transported through soils and most absorbing media with comparative ease. Moreover, the chlorides of the alkalies and alkaline earths are readily soluble. Chlorides should be expected, therefore, to accumulate in preponderant masses at the surface, which under arid and semiarid conditions they generally do.

The preponderance of sodium chloride over other chlorides is readily explicable. It is well known that when solutions of chlorides are poured through columns of soil or similar substances, offering a large surface of contact to the solution, there is a well-marked selective absorption, the soil tending to withdraw the base from the solution to a decidedly greater extent than the acid, with the result that the leaching generally contains free acid. So far as the experience we have goes, it would seem that in general soils absorb potassium most readily, then magnesium, calcium, and sodium in the order named. Supposing the hydrochloric acid when found in the lower layers to be neutralized with a mixture of these bases, as it rises in the capillary movement there is always a tendency, owing to the selective absorption of the soil, toward a lagging behind of the potassium, a lesser lagging of the magnesium and calcium (these bases probably tending also to form the much less soluble sulphates and carbonates) and a much less lagging of the sodium. In consequence, sodium is the predominating base in the readily soluble salts at the surface.

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[a] Bul. No. 228, U. S. Geological Survey, 1904.

[b] Bul. No. 30, Bureau of Soils, U. S. Dept. Agr., 1906.

The interaction of rain and irrigation waters and the sodium chloride in the surface soils with the gypsum or limestone, or both, usually found in large masses at slight depths, with the formation of the sulphates or the carbonates of sodium, and the chemical classification of alkali upon this basis is discussed elsewhere and only needs passing mention here.

To sum it up, it must be concluded that our knowledge of the origin of alkali is not yet thoroughly satisfactory and that additional laboratory and field observations are needed before a definite statement concerning this subject can confidently be made.

KINDS OF ALKALI.

Alkali is most commonly spoken of by irrigation farmers as white alkali or black alkali, depending on the color of the incrustation on the surface of the soil. This classification will probably always continue in common use, but it is not altogether satisfactory. The substances which form the alkali of arid countries are mainly the chlorides, sulphates, and carbonates of sodium, calcium, and magnesium, or a mixture of two or more of these salts. Other substances may occasionally be found, but they are relatively unimportant. Generally speaking, alkali consists of three principal ingredients—common salt or sodium chloride, Glauber's salt or sodium sulphate, and sal soda or sodium carbonate. Sodium carbonate is the principal ingredient in black alkali, and on account of its corrosive action on vegetable matter usually makes a brownish or black stain on the soil; hence the name black alkali. Since sodium carbonate may occur in large quantities in the soil and yet no dark color appear, but a white incrustation instead, the name black alkali is apt to be misleading. Again, some of the lime salts (calcium chloride) may impart a dark stain to soils, and while the injurious effect of this salt is not comparable with that of sodium carbonate, yet because of this dark stain it is usually considered black alkali by the irrigation farmer. In the accumulations commonly known as white alkali no sodium carbonate occurs; the color is not always white and the name is also apt to be misleading.

In making maps to show the distribution of alkali the practice in this Bureau has been to classify an alkali as white when no sodium carbonate is present and as black when this salt is found in the soil in considerable quantities. Since the sodium salts largely predominate, the various classes of alkali are commonly referred to as simply chlorides, sulphates, or carbonates. These salts are especially distinguished because they differ greatly in their effect upon growing vegetation; the carbonates are most toxic or injurious to plant growth, while the sulphates are least injurious.

ACCUMULATION OF ALKALI IN THE SOIL.

The accumulation of alkali in the soil, whether at the surface or many feet below, is an interesting process and deserves much more detailed consideration than has yet been given to it. The conditions which have caused accumulation vary considerably in different districts. In some places it is found that large accumulations of alkali have occurred at the surface; in other districts the accumulations are lodged several feet below the surface, and these conditions have been observed before the use of irrigation water. In many districts little or no alkali was apparent in the soil until irrigation was practiced, but with irrigation alkali accumulations began to appear and to increase continually so long as irrigation was carried on.

As has been shown in the comparison of the soils of arid regions with those of humid regions, the former contain large stores of water-soluble mineral matter. Hilgard, as a result of studies in California, states that few upland soils in the arid regions of that State contain less than from 2,000 to 2,500 pounds of soluble salts per acre in the first 4 feet. The only time this soluble mineral matter can move about through the soil is when it is dissolved in water. Means, in the report of the soil survey around Fresno, Cal., has discussed quite fully the ways in which salts move within the soil, and the following account is largely adapted from that report:

MOVEMENT OF ALKALI SALTS WITHIN THE SOIL.

The movement of alkali salts may be caused (1) by diffusion in the soil moisture, (2) by the force of gravity in moving the soil moisture downward, (3) by surface tension or capillary action, which moves the soil moisture in any direction.

(1) *Diffusion.*—The diffusion for salts or mixtures of salts in the water is so low that compared with the movement by gravity and surface tension the effects are practically negligible.

(2) *Force of gravity.*—When water is applied to the surface of the soil the force of gravity, assisted by surface tension, pulls the water

down into the capillary spaces. Soils will hold a certain percentage of water by capillary forces alone, and any excess over this percentage will drain away. This excess is called gravity water. When the surface of the ground is flooded, both surface tension and gravity act in pulling the water downward. Since the rate of flow of water through capillary spaces depends upon the size of the space, the flow through the large capillary spaces, root holes, worm borings, and animal burrows is very much greater than that through the true capillary spaces. When water is applied, the downward movement by gravity is almost entirely through the larger noncapillary spaces, while the true capillary spaces are filled by surface tension from the noncapillary spaces. In this way the salt which is dissolved by the descending water is probably to some extent drawn back into the capillary spaces, where there is very little downward movement, and remains there, only escaping out into the channels of downward movement by diffusion. The amount of salt which is washed downward by a heavy flooding is therefore not so great as would be expected.

(3) *The greatest movement of alkali salts is due to capillarity which operates through surface tension.* When water moves by surface tension, the films around the soil grains move. As soon as the gravity water has drained away, the movements become entirely by surface tension. A loss of water due to evaporation changes the curvature of the water films and starts a capillary movement toward the point where the evaporation takes place. But when water moves by capillary action it is the water in the smaller spaces that moves, and not the water which is in the larger noncapillary spaces. Therefore the water which was drawn back into the capillary spaces and which carried some of the alkali salts as it flowed down into the soil starts upward and carries with it the salts in solution. The evaporation of an inch of water on the surface of the soil accumulates on the surface all alkali salts which were contained in that inch of water, while, on the other hand, the same volume of water leached down through the soil would probably not leach out an equal amount of the salts. From this it will be seen that the tendency of the alkali salts under irrigation is to move upward perhaps more rapidly than downward.

From the above discussion it appears that surface tension or capillary attraction, as it is commonly called, is the most important agent in the movement of alkali salts toward the surface of the soil. Therefore, a soil which would permit the most rapid movements would be the most likely to accumulate alkali salts upon the surface. If two soils with different capillary powers were placed side by side, with the level of standing water the same, the soil which raised the water to the surface the more rapidly would the sooner accumulate an alkali crust.

POSITION OF MAXIMUM SOLUBLE SALT CONTENT IN THE SOIL.

In an arid or semiarid region, with the water table many feet below the surface, the bulk of the soluble salts will usually be found some distance from the surface of the soil, depending to some extent on the depth to which the annual rainfall penetrates. This means that the rainfall is not sufficient to wash the soluble salts originally contained in the soil to any great depth, but is sufficient to wash the salts down from the upper part of the soil. In sandy loams, where the rainfall does not penetrate to any considerable depth, the great quantity of salts will be found from about 3 to 4 feet. In the case of a coarse sand soil in the same district the rainfall will penetrate deeper, and therefore the salts will be washed to a greater depth, probably from 4 to 8 feet. These approximate depths at which the bulk of the salts was found were observed by Means in the Fresno, Cal., district, with an annual rainfall of about 8 inches. In the Imperial Valley, California, Holmes found the greater part of the alkali salts in virgin soils at a depth of 18 inches. In this district the rainfall is about 3 inches. In Ventura County, Cal., with an annual rainfall of about 15 inches, in sandy loam soils in their natural state, Holmes found the bulk of the soluble salts at a depth of 5 feet. In the Grand Forks area, North Dakota, with an average rainfall of nearly 20 inches, Jensen found the greater part of the soluble salts accumulated below a depth of 3 feet. These examples are given to show that in a level country with a deep water table the rainfall leaches the salts to a greater or less depth, according to the amount of rainfall and whether or not the soil is easily penetrated by the rain water. Upon evaporation of the soil moisture some of the dissolved salt returns to the surface, but as not all of the rainfall is returned by capillary action to the surface and evaporated, the greater part of the soluble salts tends to accumulate at the limit of penetration of the rains. If all of the rain water entering the soil were returned to the surface and evaporated there, accumulation of alkali at the surface would be the rule, but evaporation takes place in the soil below the surface, and the salts are held at the point of evaporation.

The high temperature which prevails in many parts of the arid regions, together with the long periods of drought, combine to keep the surface soil in a dry condition. For the greater part of the year, therefore, the capillary water column fails to come to the surface of the soil. Under such conditions it is evident that any evaporation which occurs must take place within the soil at the top of the capillary column, the water vapor escaping by diffusion through the layer of the dry soil above. Recent determinations made in the laboratory of this Bureau have shown that an evaporation of this kind does take place within the soil. Since the dissolved salts can not rise above the point where evaporation is taking place, an accumulation of salts must take place within the soil at the upper end of this capillary column. The depth of the top of this capillary column below the surface of the soil (and consequently the depth of the accumulated salts) will depend upon the ease with which the water vapor may escape by diffusion to the air above—that is, upon the porosity of the soil. We should expect, therefore, that in porous sandy soils the greatest accumulation of soluble salts would be found at a greater depth than in the case of soils of finer texture, and this accords well with field observations. This condition would result not only from the greater porosity of the sandy soil, but also from the lower capillary power of the coarser material, which would enable capillary connection with the surface to be more readily broken.

When we consider the fact that the mulching of the surface soil is used to prevent evaporation, it may appear strange that sufficient evaporation could take place through a layer of soil several feet in thickness to produce an accumulation of salts. But it must be remembered that these deposits may have been accumulating for centuries under the hot, dry environment most favorable for action of this kind.

In an arid or semiarid region it is easy to see that surface accumulations of alkali will be found in those districts where the ground water is sufficiently near the surface to permit the continuous capillary movement of the soil moisture to the surface. In such cases not only will the soluble material contained in the soil be accumulated by evaporation at the surface, but also the dissolved salts held in solution by the shallow ground water. And so we generally find basinlike depressions surrounded by sloping lands incrusted with heavy coatings of alkali. In this case the drainage from the slopes is toward the low ground and, with a permanent capillary connection between the moist subsoil and the surface, the surface in time becomes heavily incrusted with alkali.

PROBLEM OF THE FARMER IS TO PREVENT ACCUMULATION OF ALKALI AT THE SURFACE.

Having in mind the above discussion of the movement and position of the soluble salts in arid soils under natural conditions, it is at once seen that the most important problem for the irrigation farmer is how to prevent the accumulation of these soluble salts beyond the danger point or, having a surplus already accumulated in the soil, how most economically to remove this surplus and bring the soil to a profitable state of cultivation.

It is true that not all of these soluble salts are equally injurious, and none of them is detrimental to field crops when present in very small quantities. It should be emphasized that it is the accumulation that causes damage. It is also evident that, whatever the nature of the soluble salts, they may be washed out of a porous soil if conditions be such that water may be applied to all of the surface, and after leaching through the soil be carried away in the country drainage. Not all the water applied to the surface will leach through the soil, even under most favorable conditions. A part will unavoidably be returned to the surface to be evaporated, and if vegetation exists still another part will reach the air through the plants, great quantities of water being necessary for their growth. The principles that should guide the farmer in the handling of all irrigated lands under arid or semiarid conditions that favor the local concentration of salts may be briefly stated as follows:

Apply to the surface of the soil all waters that supply the crops with moisture, when it is known that the soils contain appreciable quantities of alkali. Under no conditions whatever should one depend upon subirrigation, seepage, or percolating waters to supply the crops. It is recognized that surface irrigation is a wasteful method of applying water, but it is strongly to be recommended to overcome the inevitable rise of the salts contained in the soil.

In the growing of fruits, grapes, or tilled annual crops, such as melons, corn, and truck crops, it may often be the best practice to apply the bulk of the water by the furrow method of irrigation. At best this method is one kind of subirrigation, and should only be practiced where the annual rainfall is sufficient to wash out the salts that must accumulate at the surface in the spaces between the furrows or in the tree rows; or, where this rainfall is insufficient, furrow irrigation should be accompanied by periodic smoothing and flooding to leach the salts downward. Therefore, the first requisite is so to control the application of the water that the main movement of the water will always be downward, and for at least a part of the time downward over the entire surface.

In every practicable way prevent evaporation from the surface. It has been shown that even with the most careful methods of application of water a part will be evaporated from the surface. When the water supply is so small that flooding becomes expensive, it is often more economical to cultivate thoroughly in order to retard the rise of the salts to the surface in the fields tilled, and thus lengthen the time between successive smoothings and floodings. Careful and frequent cultivation will produce a mulch that will do much to retard evaporation.

If crops are grown that admit of flooding in the application of water, there will be no danger of an accumulation of alkali, provided (*a*) the whole surface be covered with water during floodings and (*b*) the level of standing water be not so close to the surface as to permit the capillary power of the soil to make connection between this ground water and the surface of the soil. One of the most fruitful causes of alkali spots in any region given over to general flood farming is the carelessness on the part of the farmer in not thoroughly smoothing his land before beginning operations. If there be high spots, these are subirrigated whenever the remainder of the field is flooded; and, as in the case of furrow irrigation, the salts thus accumulated remain unless washed out by the rainfall or by artificial applications of water. In many cases the rainfall is insufficient to do this, and artificial applications of water or irrigation is impossible until they are smoothed.

When the water table is so close that capillarity can bring the water to the surface, the greatest care must be exercised to prevent evaporation. Not only must all the above precautions be taken, but the soil must be watched at all times and the surface mulch be maintained upon the removal of the crop. In many of the soils of the arid regions, especially in the fine sandy loams that are so prevalent, the capillary powers are very great, and the rapidity with which water moves through the soil is correspondingly great. Briggs[a] has shown that the height to which water will move in a moist sand is about 4.5 times as great as the same movement in a dry soil. His researches show that in a moist sand water will be raised more than 5 feet. For these fine sandy loams it will be readily seen that the height will be much greater, so that the surface evaporation and consequent accumulation of alkali will, if not checked by farm practices, take place rapidly in these soils when the water table is so far beneath the surface as not in itself to injure ordinary crops. These fine sandy loams are often found in their virgin state with a high percentage of alkali, yet with the water table at from 9 to 12 or even 15 feet below the surface, while adjoining sandier soils with the same water table are comparatively free from salts. In such instances it is obvious that more careful treatment is necessary for the fine sandy soils than for the coarser ones.

SUBIRRIGATION THE MOST FRUITFUL CAUSE OF SURFACE ACCUMULATIONS OF ALKALI.

In this connection it is perhaps advisable to emphasize the fact that subirrigation is one of the most fruitful causes of surface accumulations of alkali salts. The average man who starts farming on dry alkali-free soil has no thought but to supply his crops with sufficient moisture. All his efforts are to accomplish this, which to him seems the greatest problem in cultivating arid soils. If he is so situated that the irrigation taking place on higher lands with its accompanying seepage raises his water table to within capillary reach of the root zone of his crops, he suddenly finds his greatest problem apparently solved. He no longer has to irrigate to supply his crops with moisture. If the roots of his crops are not actually submerged, the first effect of this subirrigation is to increase enormously his yields of crops, and he hails with joy this new order of things that has minimized his labor and multiplied his yield. The percolating waters have taken up soluble salts, some of which are those needed by crops, but the greater quantity of which are the salts forming alkali. Supplied at all times with a favorable amount of moisture and with mineral nutrients in abundance, it is small wonder that the first stages of subirrigation are marked by record-breaking yields. But little by little the evaporation from the surface causes an accumulation of soluble salts. The slight rainfall carries a part of these salts downward into the soil, but seldom is this sufficient to carry them to the percolating sheet of water below, and the capillary rise again tends to carry them to the surface. So, nearly all the salts left behind by evaporation remain in the soil. The rate at which the salts accumulate will depend upon the amount of water the soil can raise to the surface. This amount will be greatest in a fine sandy loam, for in such a soil nearly all the spaces are capillary spaces, and yet the soil is not so dense as to offer great resistance to the movement of water. Thus under conditions of subirrigation it is always these soils that carry the greatest accumulations of alkali, and they are always the first to suffer. But in any case where the soils are not actually swamped the accumulations are so gradual as not to cause alarm until the soils are so affected that some spots cease to be productive. If the remainder of the field continues to produce fair crops, the farmer seldom recognizes the true cause of these unproductive spots and continues to depend upon subirrigation. The ultimate ruining of the land is inevitable. This period of inactivity of the irrigator on lands that are subirrigated, yet do not actually need artificial drainage, is the ruin of by far the greatest percentage of lands that were once productive, but now contain alkali beyond the point of endurance of the crops.

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[a] Capillary studies and filtration of clay from soil solutions, Bul. No. 19, Bureau of Soils, 1902.

The discussion so far has dealt mainly with ordinary irrigated soils, in which it is assumed that there are no harmful accumulations of alkali at the beginning of the operations.

The same rule—the application of all waters to the surface so as to insure a downward movement, and the prevention as far as possible of evaporation from the surface—applies to the reclamation of alkaline lands as well, except that in this case no method of applying water except flooding should be used. If such precautions as outlined above be taken, lands originally free from salts should remain so, and alkali lands should steadily become better, provided the regional drainage of the country be good.

The general discussion of the reclamation of lands heavily impregnated with alkali will be considered in another part of this paper.

INJURIOUS EFFECTS OF A FLUCTUATING WATER TABLE.

One making a study of the subject of the drainage and reclamation of alkali lands can not help but be impressed by the fact that not in all cases is the entire damage due to alkali. Because of the great depth of the soil in all arid regions, fruit trees, vines, alfalfa, and other perennial crops, as well as the ordinary annuals, develop a much deeper root system than is the case in humid regions. In the case of annuals very little damage is done by the water table itself, for the crops can each year develop a root system that will be best suited to the moisture zone. But in the case of the perennials this is not so. Many instances are on record where, with a low water table, alfalfa, grapes, and fruit trees have sent their roots down to great depths. With a light soil and favorable conditions many of the feeding roots of such plants are from 4 to 8 feet below the surface. If from any cause the water table is raised and submerges these roots, the plants will immediately show signs of suffering. In fruit trees this is usually manifested by "dieback" in the new growth, or if the rise be rapid, so that they can not develop new feeding roots above the water, the trees may be killed. Grapes show the effects of this ground water by a stunted growth, but readjust themselves more quickly than trees and are seldom entirely destroyed. Alfalfa turns yellow, gradually dies out, and the field may become entirely barren. Few of the common crops grown in arid regions will maintain a root system that is actually submerged in water, nor will they send their roots into the water. Often orchards may be observed in a very bad condition, with the trees struggling for life because of the encroachment of the water table upon their root systems, while orchards of the same trees on similar adjoining lands are in a thriving condition, the latter having been planted since the rise of the water table, and hence having developed their root system above the water table. Alfalfa fields that have been killed out by the rise of the water table may often be reseeded and will produce a good crop, because of the shallow development of the new root system. Thus it is the fluctuation rather than the shallowness of the water table that causes damage directly to the plants.

If the fluctuation be annual or periodic the difficulty of maintaining cultures that have a tendency to develop a deep root system in seeking the most favorable moisture conditions is greatly increased. At each subsidence of the water the feeding roots follow down, to be swamped at the succeeding rise. Thus it will be seen that a fluctuating water table within the possible zone of root development is in itself a serious menace to perennial crops. Walnut trees have been observed in southern California that were suffering from submerged roots when the water table was below 12 feet, while a few miles away trees over 30 years old were in excellent bearing condition on land that had never had a water table below 6 feet. At Fresno, Cal., many orchards have died when the soil showed such small amounts of salts that the damage could not have been from alkali. Near Tempe, in the Salt River Valley, Arizona, fruit growing has almost ceased because of the killing out of the older orchards by the ground water, even on practically alkali-free lands. Instances might be multiplied where injury has resulted from this cause. There is hardly an irrigated district where perennials are grown that could not furnish such specific testimony.

Investigators have frequently overlooked this important feature of the problem, and have attributed all the injury to the rise of alkali. There can be no question that this feature is of vital importance. Since it is so closely allied to the alkali problem it seems just to consider the two together. Any method that would improve the alkali condition but aggravate this evil would necessarily result in limiting the number of crops that might be grown. Moreover, fruits and alfalfa are at the present time the main crops of the irrigated regions, and the object of reclamation is very often to enable these crops to be grown. Since it is the fluctuation of the water table that causes damage from water alone, and since it has been shown that lands not drained below the reach of capillarity may be reclaimed from alkali, it must appear that, considering the two problems jointly, the method of treatment that will prevent fluctuation of the one, and at the same time result in reclamation from the other, is the most desirable. Thus considering jointly the problem of alkali and fluctuating water table, as well as the means for lowering the water table, it will be seen that the least fluctuation will take place where gravity drains are used. Pumping plants will usually be operated periodically, and hence will allow of fluctuation. Unless the water be lowered beyond the reach of the roots of plants and the fluctuations thus take place below the root zone, drainage by means of a pumping plant, while it would permit of the reclamation from alkali, would aggravate the injury from seepage water. To accomplish the desired object with gravity drains they should be constructed in sufficient detail to remove readily any surplus of water that might at any time be added to the district. The detail necessary to do this will be dependent upon the nature of the soil and subsoil and the sources of accessions of the ground water. If much of such water comes from seepage from canals, cut-off drains to catch this seepage may be a partial preventive. But in every case the detail must be worked out for the individual area, keeping in mind this two-fold object of drainage.

RESISTANCE OF PLANTS TO ALKALI.

Just what amounts of the various kinds of alkali can be endured by different plants has been the subject of investigation for many years. It has long been known that some plants—as, for example, young alfalfa—are very sensitive to alkali, while other plants, such as sorghum, can be grown on land containing so much alkali that it would be fatal to the more sensitive plants. Again, we find that not all of the soluble salts commonly called alkali exert equally injurious effects on cultivated plants. Thus black alkali, or sodium carbonate, is most dreaded by farmers of irrigated districts on account of its corrosive action on vegetable matter, while, on the other hand, they recognize that some of the forms of white alkali are not especially injurious unless accumulated in excessive amounts. Under natural conditions the experienced farmer learns to judge land by the vegetation that flourishes prior to irrigation. The growth of some bushes, he has learned through observation and experience, indicates that the soil contains accumulations of alkali, even though it may not appear on the surface. Other natural vegetation tells the farmer that the soil contains no alkali. In the States of Montana, Wyoming, and Idaho greasewood (*Sarcobatus vermiculatus*) is considered indicative of alkali in the soil, although there may be no surface manifestations denoting its presence. In some districts, however, the farmer has learned that only the abundant growth of small stunted greasewood denotes alkali in the soil, while a large-sized, scattering growth of the same plant means an alkali-free soil. Not all of the native grasses and plants can be taken as an absolute indication of the presence or absence of alkali. The common salt grass (*Distichlis spicata*) is usually considered indicative of at least some alkali in the soil, yet it has been found growing on alkali-free soil. Again, it has been observed that in one locality the plants and weeds may be regarded as denoting certain conditions of soil as regards alkali, while in other localities the same growth may not indicate similar soil conditions, but perhaps the very opposite. And so while in general the relations of plant life to alkali have been worked out, the exact amounts of alkali that can be tolerated by various crops is a problem much more difficult, and as yet not altogether understood. As Loughridge[a] has pointed out, there are many conditions which confuse the problem, such as climatic conditions, the possible presence of insects or diseases, imperfect physical condition of the soil and subsoil (hardpan, for instance), high-water table, shallowness of soil, lack of ventilation and aeration, poor moisture supply, etc. The variability in the composition of the alkali still further confuses the problem. Then, too, while we may find a crop growing on certain soil which shows on analysis a certain percentage of alkali, we have no definite knowledge that the soil in direct contact with the small feeding roots contained a similar alkali content. A given soil that contains a certain amount of alkali may support a good growth of a crop, but unless the life history of the crop is known no definite statement can be made as to the amount of alkali that was present in the soil at the various stages of the plant's growth. For example, in the Bear River Valley, Utah, Jensen found sugar beets growing on soil that contained upward of 3 per cent of alkali—mainly sodium chloride—in the surface foot of soil, with smaller amounts in the soil below this depth. From this we can not assume that the sugar beets actually withstood 3 per cent of alkali, for at the time the young beets were started heavy rains and irrigation had leached so much alkali from the soil that it contained no more than could be tolerated by the young plants. The large accumulation in the surface foot took place later in the season, and at the time the examination was made the beets were undoubtedly drawing their moisture supplies from the second foot, where the soil did not contain excessive amounts of alkali.

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[a] Tolerance of alkali by various cultures, Cal. Expt. Sta. Bul. No. 133.

The texture of the soil must be considered in determining the resistance of crops to alkali. With equal amounts of alkali in a sandy and clay soil in the same district crops will suffer more on the sandy soil. This is because the sandy soil retains a smaller amount of moisture than the clay soil, and the soil solution is more concentrated and is more easily able to exert a toxic effect on plants.

Of the sodium salts—usually the predominating salts found in alkali soils—carbonates are the most injurious, chlorides come next, while sulphates are least injurious to plant growth. Since it is seldom that one of these salts constitutes all of the alkali found in soils, it is difficult to determine definitely under field conditions the exact amount that can be endured by different plants. In the Baker City area, Oregon, Jensen obtained results that are of interest as showing resistance to alkaline carbonates. Here he found oats growing well with 0.08 per cent in the soil at the root crown, traces of neither chlorides nor sulphates being present, while in other places he found that less amounts were injuring the crop. With sulphates present it was found the crops would not stand as much of the alkali carbonates. Perhaps some of the sulphate was magnesium, a salt which Kearney and Cameron[a] found to be more injurious in pure solution than sodium carbonate. Wheat in this area was found to be growing well with 0.04 per cent alkaline carbonates in the soils. Alfalfa was likewise making good growth on soil with 0.08 per cent alkali carbonates, but the crop had been established for some time. These figures serve to give an idea of the endurance of plants in this particular area and show that from 0.03 to 0.08 per cent was about the range of amounts that could be tolerated by crops under field conditions.

In making alkali surveys in the different areas it is the custom of this Bureau to divide the land into six different grades, the relative extent of each grade of alkali land being shown on colored maps.

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[a] Report 71, U. S. Department of Agriculture.

The soils of these different grades contain from 0 to 0.20 per cent of total salts and less than 0.05 per cent of black alkali; from 0.20 to 0.40 per cent of total salts and from 0.05 to 0.10 per cent of black alkali; from 0.40 to 0.60 per cent of total salts and from 0.10 to 0.20 per cent of black alkali; from 0.60 to 1 per cent of total salts and from 0.20 to 0.30 per cent of black alkali; from 1 to 3 per cent of total salts and more than 0.30 per cent of black alkali, and more than 3 per cent of total salts—this scale representing the average of the quantity of salts contained in each foot to a depth of 6 feet. Generally it has been the experience of field parties that on land containing from 0 to 0.20 per cent of total salts none of the common crops are injured unless carbonates greatly predominate or unless practically all of the salt is concentrated in the upper part of the first foot. On land containing from 0.20 to 0.40 per cent of total salts and from 0.05 to 0.10 per cent of black alkali all but the most sensitive crops will grow, but near the higher limit all classes of plants excepting those truly resistant show signs of distress, and if the condition remains unchanged the death of the plants sometimes results. Alfalfa, when well started, grows on this class of land, but it is often difficult to secure a good stand. Sugar beets, sorghum, and barley may be grown with profit, provided precautions are taken in starting the crop. Often a heavy irrigation before seeding will result in the movement of the salts toward the subsoil, and by the time they return to the surface the crop may have sufficient stand and vitality to endure the injurious effects of the salts.

The grade of land containing from 0.40 to 0.60 per cent of total salts and from 0.10 to 0.20 per cent of black alkali contains a little too much salt for the common crops. Such lands are generally devoted to pasture, although in some areas, by thorough preparation of the seed bed, and by heavy irrigation to insure a downward movement of the salts, sorghum, sugar beets, and alfalfa have been made to produce partial or full crops. Generally only the most resistant fruits will succeed on lands of this character.

Soil containing from 0.60 to 1 per cent of total salts is almost worthless for general farming or fruit growing, but by continued effort some of the most resistant crops may be grown. The last grades are likewise worthless for farming purposes. It should be stated, however, that even with an average of 3 per cent of salts in 6 feet of soil conditions may be such that crops can be grown, much depending upon the position of the salt in the 6-foot section, whether it is evenly or irregularly distributed. By copious irrigation crops may be started and even matured on land containing 3 per cent of alkali, provided the maximum alkali content is in the lower part of the 6-foot section and evaporation at the surface is so checked that the alkali does not accumulate at or near the surface. With such excessive amounts of alkali as 3 per cent in the soil to a depth of 6 feet the chances for surface accumulation are very favorable, and generally such land has no value for farming purposes.

Of the crops usually grown in the irrigated districts of the West, Kafir corn, sorghum, sugar beets, and barley are probably the most resistant to alkali. Kafir corn and sorghum are especially important in districts containing alkali, since they will stand heavy flooding of the land during the growing period. With a deep water table and a porous soil these crops can be grown while the field is being reclaimed. Sugar beets are likewise resistant, but can not be grown in wet soils. Alfalfa is also quite resistant after a good stand has been secured, but in its younger stages it is a sensitive crop. Wheat and corn are usually classed as sensitive to alkali. Rye and oats are undoubtedly quite resistant, although not as thoroughly tested as some of the crops previously mentioned.

In discussing the resistance of various fruits to alkali it is interesting to quote from Swingle.[a]

> The immense superiority of the date palm over all ordinary crop plants for culture in alkaline lands becomes evident when it is remembered that all ordinary useful plants, such as wheat, corn, and alfalfa, peach, orange, and prune trees, etc., are killed by as much as 0.5 or 0.6 per cent of alkali in the soil, which amount is entirely without influence on the date palm. The more resistant crop plants, such as barley, sorghum, sugar beets, grapevines, olive trees, and possibly pomegranate, jujube, and pistache trees, are able to withstand from 0.6 to 1 per cent of alkali; but these plants are easily injured by an accumulation of the alkali at the surface, which is perfectly harmless to the date palm. About the only crop plant which can withstand considerably over 1 per cent of alkali is the Australian saltbush (*Atriplex semibaccata*), and even this forage plant can not endure nearly as much alkali as the date palm—probably not half as much. As previously noted, asparagus is able to endure much alkali, though the limits of its resistance have not yet been determined. The date palm is, then, the most resistant to alkali of all plants now known capable of commercial culture in arid regions.

The above paragraphs are given to show some of the relations of different agricultural products to alkali, and are not intended to give the exact order found in each locality. This can only be determined after much painstaking study, if indeed it can be determined at all.

RÉSUMÉ OF THE WORK OF THE AGRICULTURAL EXPERIMENT STATIONS ON ALKALI SOILS.

For many years the various experiment stations of the Western States and Territories have been investigating alkali soils and irrigation and drainage waters, and have gathered a valuable store of information on these interesting subjects. This work is summarized below, the States being taken up alphabetically.

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[a] The Date Palm and its Utilization in the Southwestern States, by W. T. Swingle. Bul. 53, Bureau of Plant Industry, U. S. Dept. Agr.

ARIZONA.

In 1898 Forbes[a] described the soils of the Salt River Valley. The valley is described as the most important agricultural district in Arizona, containing about 457 square miles under irrigation. In a general chapter devoted to the nature of the soils the alkali salts are briefly described. The amount of alkali salts which may exist in a soil without injury to vegetation, it is stated, depends on the kind of salts, the character of the soil, and the crops. A large number of samples of virgin soils were collected and chemical analyses made of them. Data were also obtained showing the rate at which water leached through soils, and studies were made of the capillary power of the soils to lift water. In general, it was found that water leached from the sandy soils very rapidly, while it leached from clay soils with exceeding slowness. The capillary motion of water was shown to be correspondingly slow in heavy soils and rapid in sandy soils. Analysis of a soil south of Tempe that supported only a growth of some species of Atriplex (saltbush) and other hardy plants showed upward of 4 per cent of soluble salts, in which sodium chloride largely predominated, with some traces of sodium sulphate and sodium carbonate. This soil was found to be almost impervious to water. Its capacity for holding hygroscopic moisture was likewise considerable, which was attributed to the fact that common salt, or sodium chloride, attracts moisture. After part of the salts had been leached from the soil it lost to a great extent its hygroscopic moisture.

In a chapter on general conditions in the Salt River Valley it is stated that alkali salts are present in excessive amounts in the heavy soils just south and southwest of Tempe. It is pointed out that gypsum can not be used as an antidote, since the soil contains white and not black alkali. Drainage is recommended as the method to be used in reclaiming these lands by the entire removal of the objectionable salts. The Australian saltbush, it is stated, may prove useful on alkali soils on account of the quantity of alkali it can endure.

In 1900 Forbes[b] describes black alkali and white alkali as they occur in Arizona. Black alkali is said to be formed by the decomposition of granite rocks when the rainfall and drainage are not sufficient to carry it away; hence it remains in the soil. In southern Arizona black alkali does not occur in excessive amounts, except where irrigation has caused concentration of the alkali salts. The occasional heavy downpours of rain are said to sweep away large amounts of soluble alkali salts, since it has been observed that the composition of Salt River actually changes in times of flood. The tilth of clay soils is injured more by black alkali than is the tilth of sandy soils, and 0.10 per cent of black alkali in the top 2 feet of soil was found destructive to most crops. Black alkali, besides injuring the tilth of soils, dissolves in the presence of water the humus in the soil and allows of its removal. The worst effect of black alkali is said to be its corrosive action upon the plant at or near the surface of the ground, where it forms a crust in dry weather. When drainage is possible, flooding is advocated to wash the salts down and carry them away in the country drainage.

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[a] Salt River Valley Soils. By R. H. Forbes. Bul. No. 28, Ariz. Expt. Sta., 1898.

[b] Timely Hints for Farmers, White Alkali, Black Alkali. By R. H. Forbes. Bul. No. 34, Ariz. Expt. Sta., 1900.

One ton per acre of gypsum is said to be able to overcome 0.036 per cent of black alkali in the surface foot of soil. When clearing land of brush, burning the brush on the roads instead of in the fields is advised, as the ashes contain black alkali.

In a discussion of white alkali consisting of chlorides and sulphates of sodium, calcium, and magnesium, it is stated that these salts result especially from the weathering of volcanic rocks. From 0.10 to 0.50 per cent is considered fatal to most cultivated crops. White alkali also does most of its damage near the surface of the ground. When in solution, it moves with the water until evaporation occurs, when it collects at the surface of the soil. Where evaporation is most rapid, the process of alkali accumulation goes on most rapidly. Hot and windy weather, then, promotes the rise of alkali.

Besides flooding to reclaim alkali land, deep cultivation is also recommended. The alkali crust is buried deeply, and more time is required for it to accumulate again at the surface, while in the meantime a crop may be started that will shade the land and prevent the rise of alkali. Every crop that grows absorbs and removes some of the alkali, so the good effect is permanent. Attention is called to the successful reclamation of alkali fields south of Tempe by this method. Furrow planting is mentioned as another expedient against alkali. The water in the furrow washes the alkali down, the seed then sprouts, and the plants soon become strong enough to withstand more alkali.

In May, 1902, the Arizona station issued, as Bulletin No. 40, a report entitled "A Soil Survey in Salt River Valley." This report embodied the results of cooperative work carried on by this Bureau (then the Division of Soils) and the experiment station. The station bore a share of the expenses of the field work, while Prof. R. H. Forbes furnished many chemical analyses of the alkali soils, crusts, and drainage waters. The results of this work will be included in discussing the work of this Bureau.

In 1902 Forbes[a] described some of the effects of irrigation in connection with the character and composition of the available water supply. Systematic sampling of the Salt, Gila, and Colorado rivers was carried on, and many chemical and physical analyses made of the samples, careful estimates, as well as chemical examinations, being made of the amount of silt carried by the irrigation waters to determine the percentage of fertilizing elements added to the soil. Determinations of the water soluble salts were also made to ascertain the effect of irrigation waters on the alkali question. The salts were found to vary greatly, depending on the height of water in the various rivers. The soluble salts were found to consists mainly of chlorides and sulphates of sodium and calcium. In the Salt and Gila waters during some floods considerable quantities of sodium carbonate were found. It is pointed out that the amount of soluble salts the irrigation waters may carry and not injure the soil depends on the crop grown, the natural drainage of the soil, and the methods of cultivation and irrigation. Where all of these are most favorable a large amount of soluble salts in the irrigating water need not necessarily be feared. On the contrary, land with a scant water supply receiving shallow or insufficient cultivation will in a few years show marked injury from the accumulation of alkali. Abundant flooding is recommended to distribute accumulations of alkali through the soil and carry a part of it into the country drainage. The danger of irrigating in furrows that are seldom if ever disturbed is shown by comparing analyses of soils completely flooded with soils flooded only in the bottom of the furrow. Evaporation from the exposed soil eventually results in the accumulation of alkali along the top of the furrow. Where furrow irrigation is necessary, occasionally leveling the furrows by deep and thorough cultivation is advisable, not only to check the rise of alkali in the soil, but also to economize the water. In the case of such crops as strawberries, which maintain a constant ridge, it is related that in two and a half years a strong crust formed on the ridge, while the bottom of the irrigating furrow was completely free from alkali. In such cases rotation with crops that are completely flooded is strongly urged. The practice of the Pima Indians on the Salt and Gila reservations, who wash out accumulations of alkali by several successive floodings, is quoted. Mention is made of an orange orchard located at Guaymas, Mexico, that was still thriving after twenty-five years' irrigation with water containing considerable alkali. Here the method of irrigation is to throw up embankments about the trees, so that the inclosed space can be flooded 8 or 10 inches deep. This process is repeated at intervals, and the salts are washed down and carried away in the country drainage.

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[a] The River Irrigating Waters of Arizona, their Character and Effects. By R. H. Forbes. Bul. No. 44, Arizona Expt. Sta., 1902.

In subirrigated districts in the Salt River Valley the necessity of drainage ditches is noted in order to insure effective flooding to remove the alkali. The chemical reactions possible in the soils and irrigating waters are shown to be beneficial. The river waters carry an abundance of calcium and magnesium sulphates and chlorides that react with the black alkali or sodium carbonate in the soil, forming lime carbonate and sodium sulphate, both quite harmless when occurring in small quantities.

Careful observations were made of the effects of irrigation on certain soils, and it was found that a large increase of soluble salts, mainly chlorides and sulphates, had taken place. The carbonates found in the soil were kept under control by the beneficial reaction just referred to of the irrigating water carrying an abundance of lime salts, especially sulphates. Furthermore, it was shown that the action of sodium chloride and sodium sulphate is to soften and break up the deposits of lime hardpan, locally called "caliche." This is composed largely of calcium carbonate and is much more soluble in solutions of common salt and sodium sulphate than in pure water. After years of irrigation in the Salt River Valley the hardpan often disappeared, leaving only white granular fragments to mark its former position. In places where the hardpan does not dissolve it is thought to be because the irrigating water contains only slight amounts of sodium chloride.

Observations are also published as to the depth at which various salts concentrated after years of irrigation. In a tree row where evaporation and consequent upward movement of soil water has continued for a long time without interruption the chlorides and sulphates have concentrated at the surface, while sodium carbonate and bicarbonate were found deeper. In the furrow the carbonate and bicarbonate are washed down to the second foot, while the chlorides appear to have been more thoroughly carried away.

CALIFORNIA.

For many years studies of alkali soils and the rise of alkali have been carried on in the State of California. This work was inaugurated by Dr. E. W. Hilgard, professor of agriculture in the University of California. Practically the first publication treating of alkali in the State was in 1877, in Professor Hilgard's report to the president of the university. In this report it is stated that the term "alkali soils" is applied to all soils containing an unusual amount of soluble mineral salts whose presence is frequently made apparent by the efflorescence or "blooming out" on the surface of a white powder or crust soluble in water. Alkali is most apparent in dry weather following rains or irrigation. Later in the season it usually becomes less perceptible from intermixture with dust, as well as from failure of the soil water to rise near enough to the surface. The first rain water, dissolving the salty substances, carries them partly into the water courses, but chiefly back into the soil, whence they rise again at the recurrence of dry weather.

The immediate source of alkali, it is stated, is usually found in the soil water, which, rising from below and evaporating at the surface, deposits there whatever of dissolved matter it may contain. Such water is by no means always perceptibly salty or alkaline. The soil, acting like a wick, draws up the soil water and allows it to evaporate at the surface, where all of the dissolved salts accumulate until the soil becomes so impregnated as to injure or kill all useful vegetation. The injury will be found to be most severe just at or near the crown of the root, where the stem emerges from the soil.

The most obvious remedy for alkali is the leaching out of the salts by flooding, accompanied, if possible, by underdraining, a method habitually resorted to in the seacoast marshes near the mouths of rivers. When the water table is a few feet from the surface and contains much saline matter, or when the subsoil contains much saline matter, several remedies are proposed.

1. When the alkali is neither abundant nor noxious, frequent and deep tillage may afford all the relief needed.

2. Underdrains may lower the water table from which the saline matters are derived and may so favor the washing out of the salts during the rainy season that with deep tillage no more injurious accumulations will take place.

3. When the quantity of salt or alkali is small but is very injurious or corrosive, the application of chemical antidotes may mitigate the evil or sometimes completely relieve it. In this case it is necessary to determine by analysis the nature of the alkali.

The salts determined up to the year 1877 were:

(*a*) Neutral alkali salts, such as common salt, Glauber's salt, sulphate of potassium, etc. When present in large quantities relief can only be obtained by washing them out of the soil.

(*b*) Soluble earthy and metallic sulphates and chlorides, as Epsom salt, bittern, chloride of calcium, alum, copperas, etc. For a cheap and efficient antidote lime is recommended, and in some cases a calcareous marl is said to answer the purpose.

(*c*) Alkaline carbonates and borates. The carbonates are very injurious, even in the smallest amounts. The antidote for these salts is said to be gypsum or land plaster. These chemical antidotes should be sown or spread on the surface and plowed or harrowed in to a moderate depth just prior to irrigation. The gypsum should be put in with the grain.

An analysis of soil from Sherman Island, Sacramento County, showed the salts to consist of sulphate of magnesia, sodium chloride, and potassium chloride. Alkali soil from near Corvallis, Los Angeles County, contained sodium sulphate, sodium chloride, and sodium carbonate as the principal ingredients. The quantity of the last named is sufficient to dissolve not only dead vegetable matter but also to attack and destroy living rootlets and bark when accumulated by surface evaporation. Soil from a seacoast flat near Anaheim, in Los Angeles County, contained largely sodium chloride and calcium sulphate (gypsum), with small amounts of potassium salts, magnesium sulphates, and alkaline nitrates. These salts are substantially the materials contained in sea water.

A sample of alkali soil from Westminster Colony, Los Angeles County, contained 0.54 per cent of soluble salts, of which sodium carbonate was the principal ingredient, with small amounts of potassium sulphate, sodium chloride, and potassium carbonate. This sample was representative of certain parts of a tract of 30,000 acres. It was considered too strong for barley, but it was found that sugar beets would grow under favorable circumstances. An experiment was tried on 0.1 of an acre, applying 65 pounds of gypsum, plowing it under about 6 inches deep, and then 35 pounds of gypsum were sowed. The land was then harrowed and planted with corn. Where water stood on the surface of the soil there was a good stand of corn, but where the land was subirrigated not more than half a stand of corn was realized. The failure was ascribed to the fact that the gypsum did not come in contact with the water.

An analysis of a crust of an alkali soil from near San Jose, in Santa Clara County, showed principally sodium sulphate, sodium carbonate, and sodium chloride. The most successful attempts at cultivation of this soil have been by deep ditch drainage, copious washings by flooding, and fine surface cultivation to prevent the alkali from rising to the surface.

In 1879 Hilgard[a] reports further studies of alkali soils. Samples of soil near Stockton, San Joaquin County, were analyzed and found to contain sodium carbonate as the principal ingredient, as well as sodium sulphate and sodium chloride. Other samples from near-by localities contained the same salts, but in different proportions; in one the sulphates largely predominated, while another sample consisted almost wholly of sodium carbonate. One sample, which to a depth of 12 inches contained about 1 per cent of salts, carried largely sodium carbonate, sodium nitrate, bisodic-hydric phosphate, and lesser quantities of sodium sulphate and sodium chloride.

Alkali soil from Hueneme, Ventura County, contained sodium sulphate, magnesium sulphate, and sodium chloride as the principal ingredients. The alkali in the soil near Collinsville, Solano County, consisted of magnesium sulphate, sodium sulphate, and sodium chloride. Soil from the Emigrant Ditch region, Fresno County, consisted almost wholly of sodium carbonate, with a little sodium chloride.

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[a] E. W. Hilgard. Supplement to the Biennial Report of the Board of Regents, College of Agriculture, University of California, 1879.

Alkali soils from near Lemore, Tulare County, were found to contain as the principal salts chiefly sodium sulphate and magnesium sulphate.

In 1880 Hilgard[a] notes that, roughly speaking, there is in the State an obvious inverse relation between the rainfall and the prevalence of alkali in the soils. In the region about Sacramento the more copious rainfall seems to keep soils leached of their alkali. The general increase of alkali on irrigated lands is noted in the upper parts of the San Joaquin Valley, especially in the counties of Kern, Tulare, and Fresno south of Kings River. It is pointed out that the term "rise of alkali" is accurate, since it is emphatically true that alkali salts rise from below through the agency of water evaporating at the surface. Irrigation has not only increased the amount of water evaporating from the surface, but has also caused a much greater depth of subsoil to be drawn upon for its alkali. Each succeeding irrigation followed by evaporation tends to accumulate the salts nearer the surface, so that finally the root crowns of the crops are burnt up before even beginning to head. To prevent the alkali from accumulating at the surface, attention is called to the crust that forms, especially in clayey soils, and to the fact that means should be taken to keep this broken, thereby reducing surface evaporation. Hoed crops, which require the surface to be frequently cultivated, and alfalfa, which heavily shades the surface, are strongly recommended. Of the hoed crops, cotton, hemp, jute, and ramie are suggested among the textile crops, and beets, carrots, turnips, sweet potatoes, etc., among the root crops. Large and small fruits, especially grapes and prunes, and sorghum and sugar cane are also suggested. Cereal crops requiring broadcast culture are regarded as a poor selection for an alkali region, since such crops allow of rapid surface evaporation, with its consequent increase of the alkali content at the surface.

Subirrigation is recommended instead of surface irrigation, since the former method reduces the surface evaporation, as well as reduces the amount of water necessary. The expense of a suitable system of subirrigation pipes is brought out, but it is emphasized that the same pipes could also be used for drainage when flooding the land to leach out the injurious accumulations already formed at the surface. In a study of some of the river waters and those of Tulare Lake to determine their possible effect on the alkali condition, the waters of Tulare Lake were found to be especially harmful and to be growing worse from year to year, until the rivers leading from it all contained slight traces of alkali, plainly showing that some precautions should be taken in the use of their waters.

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[a] E. W. Hilgard. Report of the Professor in Charge to the Board of Regents, College of Agriculture, University of California, 1880.

In 1882 Hilgard[a] pointed out that, while the corrosive action exerted by alkali salts upon the upper roots or root crowns of crops is the most serious and common source of injury, when the alkali is carbonate of soda or potash there is still another effect, especially on the heavier class of soils. This is the difficulty of producing a condition of good tilth, owing to the tendency of alkali solutions to maintain all true clays in a tamped condition. The alkaline carbonates, moreover, dissolve the humus which imparts the dark color to the water standing on the alkali-spots, giving rise to the name "black alkali."

In 1886 Hilgard[b] published the analyses of several river waters and discussed their composition. The water of the Los Angeles River contains no carbonate of soda, but only mineral and earthy salts; hence the accumulation of alkali salts will only occur when its waters are more closely utilized and relatively scarcer. Kern River contains the same dissolved salts as Tulare Lake, but the proportion is 1 to 22. This river contains carbonates, as well as less injurious salts. Kings River is shown by analyses to be quite free from carbonates, but contains other soluble salts. The San Joaquin River contains some carbonates, but not so much as Kern River. From the irrigator's standpoint the waters of Mokelumne River are the best, with Kings River next. Then comes the Merced, and after it the Sacramento, and then the San Joaquin, followed by Kern River, and last of all Tulare Lake.

In 1889 Doctor Hilgard,[c] speaking of the kinds of alkali, stated that the distinction between "black alkali" and "white alkali" is important. In black alkali sodium carbonate predominates, while white alkali consists mainly of the bland and relatively innocuous Glauber's and common salt. Black alkali is many times more injurious than white alkali, not only because it directly corrodes the root crowns of plants, but also because it dissolves out the important ingredients of humus, and renders the heavier clay soils almost untillable. This latter effect is even noticed on sandy soils, which often bake badly. With white alkali accumulated at the surface the soils can be easily tilled, and only when it accumulates in excessive quantities does it injure surface roots and root crowns. Underdrainage is recommended as the general and absolute corrective of alkali. Simply putting water on the surface will not suffice unless its removal after passing through the soil is provided for. If the alkali solution descends no farther than the subsoil and remains there, it will again ascend to the surface after evaporation has commenced, and thus no permanent good is accomplished. The value of this method has been tested in California and India, and it was found that the alkali actually increased instead of decreased. To flood the land until underdrains, laid a reasonable distance apart, have run for some time will end the trouble, not only for the time being, but for centuries, unless, of course, solid beds of alkali salts underlie the soils, as seems to be the case in some of the lower lands of the Tulare Lake region. The presence of calcareous hardpan below the surface may make this process more difficult, but it can be broken in many places and the ditches dug deeper than the hardpan. Doctor Hilgard states, in further discussing the underdrainage of land, that the time is not far distant when in California the laying of underdrains will be considered an excellent investment on any land as valuable as all irrigated land is likely to be, and when that day comes "alkali" will no longer be found in irrigated lands.

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[a] E. W. Hilgard. Report on the Climatic and Agricultural Features and the Agricultural Practices and Needs of the Arid Regions of the Pacific Slope. Departmental Report No. 20 of the U. S. Commissioner of Agriculture, 1882.

[b] E. W. Hilgard. Alkali Lands, Irrigation and Drainage in their Mutual Relation. Appendix No. VII, Annual Report, 1886. Univ. of California, 1886.

[c] E. W. Hilgard. Rise of Alkali in the San Joaquin Valley. Bul. No. 83, California Expt. Sta., 1889.

Hilgard mentions, as an example of the variability of the composition of the soluble salts within short distances, the case of a 10-acre tract near Fresno on which both white and black alkali occur. In Tulare County carbonate of soda is quite generally present in large proportion, doubtless in consequence of the more general prevalence of heavy soils rich in vegetable matter, which promotes the formation of carbonate.

In 1892 Hilgard[a] discussed the influence of climatic conditions upon the chemical processes in soils. In arid regions the easily soluble alkali salts, notably those of sodium and to some extent potassium, with certain easily soluble earthy compounds—sulphates and chlorides of calcium and magnesium—are retained in the soil to a greater or less extent. This is directly due to insufficient rainfall to leach away these substances.

He points out that alkali lands are a characteristic feature of all regions of scanty rainfall and are found in all continents—in Europe in a portion of the Hungarian lowlands and in a few localities of Mediterranean Spain. Even in humid regions limited areas occur where various kinds of salts may be found. In arid regions the alkali salts are not only retained in their first soluble form, but by their continued presence profoundly influence the processes of soil formation. With an annual rainfall of 20 inches or more the retention of any considerable amount of soluble salts in the soil becomes impossible under ordinary conditions of soil and drainage. Below that limit of rainfall the degree of alkalinity is dependent more or less upon local conditions, as well as upon soil texture.

In India, Hilgard states, we find a large area in which alkali (reh) is more or less troublesome. This area extends all the way from the

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[a] Relations of Soils to Climate. By E. W. Hilgard. Bul. No. 3, Weather Bureau, U. S. Dept. of Agr.

Indus and the Arabian Sea on the west to a little beyond the Ganges on the east and from the Gulf of Cutch on the south to Afghanistan on the north, including all of Sind, Rajputana, the plains of the Punjab, the Northwest Provinces, and part of Oudh to within a short distance of the Himalaya ranges, including Lahore. Within this region the rainfall varies from a minimum of 4.3 inches at Jacobabad on the Afghan frontier beyond the Indus to over 30 inches at Cawnpoor on the Ganges. We have but scanty data as to the area of land affected by injurious accumulations of alkali salts, but all the provinces mentioned above are reported as suffering more or less from "reh." The country surrounding the cities of Delhi, Meerat, Agra, and Cawnpoor suffers a great deal. As all this country receives between 20 and 30 inches of rainfall, it is probably the distribution of the rainfall that allows the accumulation of alkali. The conditions giving rise to the alkali are quite similar to those in North America. The calcareous nature of the rocks and their tendency to form "kankar" or hardpan is pointed out. The composition of the alkali is similar to that of other countries. Much stress is laid upon the occurrence of nitrates, and nitrate of lime is mentioned as a possible antidote for carbonate of soda.

A state of affairs quite analogous to the arid West of America exists in Egypt, Arabia, Syria, and Persia, as well as in the Aralo-Caspian plains. Saline efflorescences are mentioned as obstacles to cultivation, while the shallow wells are so salty as to be almost unfit for domestic uses. The "shotts" on the northern edge of the African desert in the French colonies are regarded as hopeless alkali sinks.

The following table shows the composition of the soluble alkali in foreign localities:

Composition of the soluble alkali in foreign countries.

Region.	Potassium sulphate (K_2SO_4).	Sodium sulphate (Na_2SO_4).	Sodium carbonate (Na_2CO_3).	Sodium chloride ($NaCl$).	Sodium phosphate (Na_3PO_4).	Magnesium sulphate ($MgSO_4$).	Magnesium chloride ($MgCl_2$).	Total.
Europe:								
Hungarian plain—	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Kalccsa		0.2	48.1	51.7				100.0
Debreczin		1.6	92.5	4.4	1.5			100.0
Asia:								
Plain of the Araxes		10.4	14.7	74.6				99.7
		18.2	12.1	69.7				100.0
		15.5	69.0	15.5				100.0
Aden			67.2	32.8				100.0
India	11.1	7.0	79.0	2.9				100.0
Africa:								
Egypt		23.6	28.2	48.2				100.0
		38.3	47.7	14.0				100.0
Fezzan		.6	98.7	.7				100.0
Australia:								
Bendigo	1.28	40.05		47.47		11.20		100.0
	1.63			81.88		9.86	6.73	100.10

In this same bulletin Hilgard discusses the effect of irrigation on alkali soils. Since the occurrence of soluble salts in soils is due to the deficient rainfall and consequent failure to leach out soluble matters, it seems reasonable to expect that when the soils are irrigated the normal leaching process would soon free the soil from any excess of soluble salts. But just the opposite is true, and the reason is that the quantity and distribution of irrigation water are different from the rainfall of humid regions. Usually the total quantity of irrigation water used during the year is less than the annual rainfall of humid sections, a great abundance being used for but a short time. The irrigation water carries the alkali down with it; but as the water does not reach the country drainage when evaporation begins, it reascends, and finally, if the whole of the water evaporates, all of the alkali is left on or close to the surface. As irrigation water usually penetrates deeper than the rains, it follows that a larger quantity of alkali is carried to the surface than was there before.

In considering the reclamation of alkali land by underdrainage and flooding, it is urged that such a method is expensive, and, moreover, washes valuable plant food from the soil. Other possible remedies are suggested, as checking surface evaporation by means of deep and thorough cultivation. The use of gypsum is earnestly urged as a corrective of black alkali, as it neutralizes the sodium carbonate by forming sodium sulphate or white alkali.

Hilgard and Jaffa[a] point out the greater nitrogen content of the humus of arid soils as compared with humid soils. They are led to conclude that the alkali carbonate does not prevent the accumulation of nitrogen in humus, while under the influence of the hot sun free or carbonated ammonia is given off. Under these conditions nitrification must be greatly favored, provided the nitric ferment is not prevented by an injurious excess of the alkaline carbonate from exerting its action.

Loughridge[b] states that the presence of alkali salts in a soil produces a puddling or deflocculation of the particles when wet and a consequent compact condition which prevents the rapid rise of water. This puddling is accompanied by a large contraction of volume, a feature which to a far less degree has been observed in other soils.

Hilgard,[c] in a paper on the distribution of the salts in alkali soils, points out the great productiveness of arid soils when first irrigated, but shows that small alkali spots may appear in the course of a few years, and that, even where the irrigation water is very pure, the trouble from alkali may increase just the same.

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[a] E. W. Hilgard and M. E. Jaffa. Proceedings of the Society for the Promotion of Agricultural Science, 1890.

[b] The Capillary Rise of Water in Soils. By R. H. Loughridge. Report of the Agricultural Experiment Stations of the Univ. of California, 1893–94.

[c] E. W. Hilgard. Annual Report California Expt. Sta., 1895.

From studies carried on it was found that the main mass of the alkali salts exists in the soil and subsoil within a short distance of the surface, while chemical examination showed the alkali to consist of such compounds as are known to exist in all soils in consequence of weathering and that it contains all the ingredients useful, as well as those useless, to plant growth. He concludes that the amount of salts in alkali lands is limited and that if once removed or rendered innocuous it will take thousands of years in the future, as in the past, before another such supply can originate from the very gradual weathering of the soil mass. The rainfall in arid countries washes the soluble salts to a short distance below the surface, seldom below 3 feet, and from this depth they may partially or wholly reascend with the soil moisture and be deposited on or near the surface by evaporation during the dry season. At the lower limit of the penetration of rainfall a gradual accumulation of the saline matter probably takes place. Early in May such soils may be covered with wild flowers, as the alkali has been washed down, and the roots only penetrate to a slight depth and are not damaged by the deeper accumulation of alkali. The surface of the land being shaded and the soil moisture escaping through the plants, evaporation from the surface of the soil is restricted, and the accumulation of alkali at the surface is reduced to a minimum. A crop like alfalfa will tend to diminish or prevent the rise of alkali. Such crops may flourish for years on a soil that, if left bare during the dry season for the sowing of a fall crop, may prove altogether too alkaline near the surface and kill the crop.

Seepage water from overirrigation, or leaky irrigation ditches, by filling up the land below the alkali-impregnated hardpan, dissolves the salts and carries them to the surface. Evaporation from the moistened surface, which is going on more or less throughout the year, causes the salts to accumulate slowly at or near the surface, until the maximum amount is found there instead of 3 feet below. Surface irrigation produces the same result, since water is usually not supplied in sufficient quantities to leach out the salts, nearly all the water supplied evaporating at the surface. The irrigation water penetrates the soil to a greater depth than the rain water. Hence the salts are dissolved and carried upward from a greater depth. Any course of procedure, then, that diminishes evaporation at the surface tends to prevent the rise of alkali. Mulching and shading both produce this effect.

Hilgard[a] states that even in very pervious soils the leaching out of white alkali is greatly accelerated by laying underdrains. In the case of black alkali, he points out that either an impervious hardpan or the impenetrability of the surface soil itself will render underdrains ineffective unless the sodium carbonate, with its compacting effects on the soil, is first destroyed by the use of gypsum. This is not only necessary in order to render drainage and leaching possible, but is also advisable to prevent the leaching out of valuable humus and soluble phosphates which are rendered insoluble by the action of the gypsum, though not made unavailable to plants. Since alkali lands are very productive when reclaimed, it is advisable to attempt their reclamation, even though this may be somewhat expensive.

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[a] Origin, Value, and Reclamation of Alkali Lands. By E. W. Hilgard. Yearbook, U. S. Dept. of Agr., 1895.

Hilgard and Loughridge[a] show that on one and the same soil the lower and moister ground shows more of black alkali or sodium carbonate than the higher, and that as between heavy or clay soils and light or sandy soils in similar locations the sandy soil invariably shows less black alkali than the denser clay soil. Generally speaking, black alkali occurs mostly in relatively low or badly drained ground, and the white alkali on high or well-drained ground. The important practical conclusion to be drawn from this fact is that whenever land is thoroughly aerated—as by underdrainage—there is little danger from black alkali, and, even if temporarily formed, it will soon vanish by transformation into the white or neutral salts. Whenever, on the contrary, alkali land is allowed to become water-soaked for any length of time the neutral or white salts may be transformed into the corrosive carbonate. It is well known from experience, however, that a soil containing much gypsum is very liable to be seriously damaged by water-logging, because of the "reduction" of the sulphates to sulphides, resulting in the production of sulphuretted hydrogen—the gas of rotten eggs—which is so fatal to vegetation.

Loughridge,[b] treating of the effects of gypsum on black alkali lands, concludes, first, that the amount of gypsum to be applied to alkali soils must be about double that of the carbonate of soda present; second, that the effect is then apparent within two or three days, and third, that the effect is probably permanent in the conversion of the carbonate into the sulphate. When an excess of gypsum is used it can do no damage to the soil unless the soil should become waterlogged.

Loughridge[c] states that the effect of alkali is both direct and indirect, being direct in its action upon the trees through their roots and indirect in its action upon the physical nature of the soil, and hence upon the tree. The direct action varies with the nature of the alkali and with the quantity in the soil. Carbonate of soda is the most dangerous, because of its corrosive action on the rootlets of plants and trees.

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[a] The Distribution of the Salts in Alkali Soils. By E. W. Hilgard and R. H. Loughridge. Bul. No. 108, California Expt. Sta., 1895.

[b] R. H. Loughridge. Annual Report, California Expt. Sta., 1896–97.

[c] R. H. Loughridge. Annual Report, California Expt. Sta., 1897–98

In the Corona orchards only 960 pounds of carbonate per acre in 3 feet of soil undoubtedly caused the falling of leaves and fruit.

The chief injurious effect of sodium chloride upon plant life is that of an antiseptic whose action seems to be to arrest the development of or to kill the nitrifying organisms in the soil. Sodium sulphate is injurious in large amounts, and as it is a neutral salt its action would seem to be chiefly that of preventing osmosis of the soil solution into the cells of the roots, thus depriving the plant or the tree of sufficient nourishment for the maintenance of growth, and finally producing death.

Doctor Hilgard, discussing in the same report the use of saline and alkali waters in irrigation, states that we can apply to a fairly pervious soil an amount of saline irrigation water large enough to wash into the subdrainage any former accumulations, and when this operation is repeated at intervals not too far apart and surface evaporation is not allowed to progress to too great an extent, relatively strong saline water may be used with impunity, the plants then growing substantially under the same conditions as the luxuriant vegetation so commonly found on the margins of alkali lakes. If, however, the same water were used according to the ordinary practice of irrigators, trouble would undoubtedly arise, since the repeated shallow wettings, with subsequent evaporation, would accumulate the alkali at or near the surface.

Loughridge[a] gives the results of a number of years' observation and study on the resistance of plants to alkali. These observations were carried on at the University of California substation in southern California and at the Tulare substation in the San Joaquin Valley. He points out the conditions that may affect the interpretation of the results of alkali examinations and lead to erroneous conclusions with regard to the effect of alkali on cultures. These are climate, the possible presence of insects or diseases, and imperfect physical conditions in the soil and subsoil—such as hardpan, high water table, shallowness of soil, lack of ventilation and aeration, poor moisture supply, etc.—any of which might cause injury to the plant. All of these must be considered before the trouble can be charged to alkali. The complexity and variability of the salts still further confuses the problem.

Chemical analyses of a large number of soils were made to determine the tolerance of various crops and fruits. Some of the results are as follows:

Almonds.—The exact point of tolerance was not ascertained, but it was clearly shown that 2,000 pounds of sodium carbonate and 3,000 pounds of sodium chloride per acre to a depth of 4 feet affected the growth.

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[a] Tolerance of Alkali by Various Cultures. Bul. No. 133, California Expt. Sta., 1901.

Apples.—At the Tulare substation this tree was found to be quite resistant to alkali. The examinations showed that the apple will tolerate the presence of 14,000 pounds of sulphates, 650 pounds of sodium carbonate, and 1,200 pounds of sodium chloride. It is injured by 1,200 pounds of carbonate and 3,000 pounds of sodium chloride per acre to a depth of 4 feet.

Figs.—This tree easily tolerated 25,000 pounds of sodium sulphate and 1,100 pounds of sodium carbonate per acre in 4 feet.

Lemons.—This seems the least tolerant of all the fruit trees, for its growth was stunted by only 1,440 pounds of sodium chloride per acre to a depth of 4 feet, and was killed by 1,900 pounds combined with 1,900 pounds of carbonate of soda. Its endurance of carbonate of soda alone was not ascertained.

Oranges.—At the Tulare substation oranges seemed to do well in the presence of 3,840 pounds of carbonate and 3,360 pounds of sodium chloride per acre to a depth of 4 feet.

Olives.—The olive tree was shown to be immune to as much as 3,000 pounds of sodium carbonate and 30,000 pounds of sodium sulphate per acre to a depth of 4 feet, and the limit of tolerance will probably be found to be much above these figures. The tolerance for common salt is above 6,000 pounds per acre in the first 4 feet.

Peaches.—At Tulare it seemed probable that the limits of alkali tolerated by peach trees may be placed at 10,000 pounds of sulphates, 750 pounds of carbonate, and 1,200 pounds of sodium chloride per acre in the first 4 feet.

Pears.—The results seem to show that while the pear can tolerate as much as 1,400 pounds of sodium chloride and 1,800 pounds of carbonate per acre to a depth of 4 feet, it is seriously affected by 38,000 pounds of sodium sulphate.

Plums.—At Tulare the plum was found to be one of the most sensitive of trees to the effects of alkali salts.

Prunes.—This tree can stand large quantities of sodium chloride, at least.

Wheat.—From the results obtained it appears that wheat should do well in deep and loose soils having not more than 20,000 pounds of total alkali, if there is not more than 1,200 pounds each of sodium carbonate and sodium chloride per acre to a depth of 4 feet.

Barley.—This plant is more resistant to alkali than wheat, but was killed by 18,720 pounds of sodium carbonate.

Alfalfa.—When young, alfalfa roots are very tender and sensitive to the corrosive action of carbonate of soda, and as they are confined to the upper foot or two of the soil, they are fully within the reach of this salt. When the roots are older and have penetrated deep into the soil, the root crown has become more corky and hardened and less sensitive, so that it is able to withstand a far greater quantity of alkali. While alfalfa is easily killed by alkali when young, it will tolerate as much as 6,000 pounds of sodium chloride, 3,000 pounds of carbonate, and 102,000 pounds of sulphate per acre in the first 6 feet of soil, if it succeeds in getting a good start. It is therefore necessary, in order to get a start, that the top soil be comparatively free from alkali salts.

Saltbush.—The Argentine saltbush grew luxuriantly in soil that carried 14,600 pounds of sodium carbonate. The Australian saltbush can tolerate 156,720 pounds of salts per acre in the first 4 feet.

Sorghum.—This can easily tolerate as much as 10,000 pounds of sodium carbonate, the same amount of sodium chloride, and 75,000 pounds of sulphate of soda. It is therefore one of the most resistant of the plants tested.

Sugar beets.—The maximum of each salt tolerated by this plant in two thickly sown plats was 52,000 pounds of sulphates, 4,000 pounds of carbonate, and 5,400 pounds of sodium chloride.

Celery.—This plant will easily tolerate as much as 10,000 pounds of sodium chloride, but is killed by 30,000 pounds per acre.

Onions.—This crop grew well on land with 400 pounds of sodium chloride in the surface foot and 4,000 pounds of sulphate per acre.

Potatoes.—Near Bakersfield, potatoes grew on black alluvial soil which held in the first foot 18,400 pounds of alkali, of which 4,000 pounds was sodium carbonate and 6,800 pounds sodium chloride.

In the following table are given the results obtained:

Highest quantity of alkali salts to a depth of 4 feet by which fruit trees and various crops were found unaffected—arranged from the highest to the lowest.

[Pounds per acre in 4 feet depth.]

FRUIT TREES.

Sulphates (Glauber's salt).	Pounds.	Carbonate (sal soda).	Pounds.
Grapes	40,800	Grapes	7,550
Olives	30,640	Oranges	3,840
Figs	24,480	Olives	2,880
Almonds	22,720	Pears	1,760
Oranges	18,600	Almonds	1,440
Pears	17,800	Prunes	1,360
Apples	14,240	Figs	1,120
Peaches	9,600	Peaches	680
Prunes	9,240	Apples	640
Apricots	8,640	Apricots	480
Lemons	4,480	Lemons	480
Mulberry	3,360	Mulberry	160

Chloride (common salt).	Pounds.	Total alkali.	Pounds.
Grapes	9,640	Grapes	45,760
Olives	6,640	Olives	40,160
Oranges	3,360	Almonds	26,560
Almonds	2,400	Figs	26,400
Mulberry	2,240	Oranges	21,840
Pears	1,360	Pears	20,920
Apples	1,240	Apples	16,120
Prunes	1,200	Prunes	11,800
Peaches	1,000	Peaches	11,280
Apricots	960	Apricots	10,080
Lemons	800	Lemons	5,760
Figs	800	Mulberry	5,760

Highest quantity of alkali salts to a depth of 4 feet by which fruit trees and various crops were found unaffected—arranged from the highest to the lowest—Continued.

SMALL CULTURES.

Sulphates (Glauber's salt).	Pounds.	Carbonate (sal soda).	Pounds.
Saltbush	125,640	Saltbush	18,560
Alfalfa (old)	102,480	Barley	12,170
Alfalfa (young)	11,120	Bur clover	11,300
Hairy vetch	63,720	Sorghum	9,840
Sorghum	61,840	Radish	8,720
Sugar beet	52,640	Modiola	4,760
Sunflower	52,640	Sugar beet	4,000
Radish	51,880	Gluten wheat	3,000
Artichoke	38,720	Artichoke	2,760
Carrot	24,880	Lupin	2,720
Gluten wheat	20,960	Hairy vetch	2,480
Wheat	15,120	Alfalfa	2,360
Barley	12,020	Grasses	2,300
Goat's rue	10,880	Kafir corn	1,800
Rye	9,800	Sweet corn	1,800
Cañaigre	9,160	Sunflower	1,760
Ray grass	6,920	Wheat	1,480
Modiola	6,800	Carrot	1,240
Bur clover	5,700	Rye	960
Lupin	5,440	Goat's rue	760
White melilot	4,920	White melilot	480
Celery	4,080	Cañaigre	120

Chloride (common salt).	Pounds.	Total alkali.	Pounds.
Modiola	40,860	Saltbush	156,720
Saltbush	12,520	Alfalfa (old)	110,320
Sorghum	9,680	Alfalfa (young)	13,120
Celery	9,600	Sorghum	81,360
Alfalfa (old)	5,760	Hairy vetch	69,360
Alfalfa (young)	760	Radish	62,840
Sunflower	5,440	Sunflower	50,840
Sugar beet	5,440	Sugar beet	59.840
Barley	5,100	Modiola	52,420
Hairy vetch	3,160	Artichoke	42.960
Lupin	3,040	Carrot	28,480
Carrot	2,360	Barley	25.520
Radish	2,240	Gluten wheat	24.320
Rye	1,720	Wheat	17,280
Artichoke	1,480	Bur clover	17,000
Gluten wheat	1,480	Celery	13,680
Wheat	1,160	Rye	12,480
Grasses	1,000	Goat's rue	11,800
White melilot	440	Lupin	11,200
Goat's rue	160	Cañaigre	9,360
Cañaigre	80	Ray grass	6.920
		White melilot	5,840

The general results from the above observations are that grapes and olives stand at the head among the fruits in their tolerance of each of the alkali salts. The quantity tolerated depends largely upon the distribution of the several salts in the vertical soil column, the injury done by the alkali being most severe in the surface foot, where the feeding rootlets are usually found. Methods of culture and irrigation are recommended that will encourage deep rooting on the part of crops. The quantity tolerated also varies with different varieties of the same plant. The quantity tolerated by different plants likewise varies with the nature of the soil, being lowest in heavy clay and fine-grained soils in which the downward growth of plant roots is restricted, and highest in loam and sandy soils in which the roots have greater freedom of penetration.

Some plants, such as saltbush and alfalfa, are quite susceptible to alkali when young, but when the roots penetrate deeply and the ground is heavily covered with the foliage of the plant they are largely immune.

In a report[a] on the lands of the Colorado Delta, in the Salton Basin, the classes of alkali contained in the soils are discussed and recommendations given for the treatment of the soils. Many samples of soil were collected and analyses made of them. The content of alkali salts was found to vary greatly within short distances. It is pointed out that sooner or later there will arise the necessity of drainage canals to keep the seepage water from swamping the lower land. With this underflow of water there is greater or less accumulation of alkali salts in the lower areas, which, taken in connection with the naturally high lime content of the soil, is almost sure to result in the formation of considerable black alkali, a condition which could even then be seen in a few localities.

In considering only the quantity of alkali salts in the soils of this region it was found that the outlook was not altogether encouraging. While there was some land not too strongly impregnated to produce, without any special precautions, good crops of cereals, especially barley and alfalfa, there was a very large proportion of the land so strongly charged that, without due care, crops could be secured only for two or three years and in some cases none at all. In the great majority of cases there was a great predominance of sulphates. Carbonate of soda was found to be quite subordinate because of the presence of gypsum throughout the valley. Sodium chloride was rather abundant near the surface.

Shinn,[b] in the annual report for 1898–1901, gives the results of the alkali reclamation work at the Tulare substation. The solution of the alkali problem, as set forth in previous publications, is stated as follows: Control of irrigation, control of drainage, study of the extremely varying kinds and degrees of alkali, and use but not waste of gypsum to neutralize carbonates.

An experimental tract of 20 acres of alkali land was selected surrounded by land strongly impregnated with alkali. This sloped irregularly from northeast to southwest, and was traversed by old slough channels. The alkali consisted largely of carbonates, and gypsum was used to neutralize the carbonate to the relatively innocuous sulphate. Charts accompany the report to show the progress made in the reclamation. Work was started in 1889, and the soil at once showed the effects of the application of gypsum. In 1893, however, partly reclaimed land showed the beginning of a rise of alkali due to the wet seasons, and the gradual amelioration of the worst areas by cultivation and the use of gypsum. In 1896 the charts showed increase of alkali and loss to cultivation of much of the land that had been reclaimed, due doubtless to increased irrigation of surrounding lands. After this serious rise of alkali in 1896 a second drainage pit was cut through to gravel and a deep ditch was dug to intercept the flow of water from the north side, and more gypsum was applied. The alkali yielded to this treatment, the accumulation of alkali was prevented, and crops were harvested on much of the land that originally could not be cropped at all.

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[a] Lands of the Colorado Delta in the Salton Basin. By E. W. Hilgard, F. J. Shaw, and G. W. Shaw. Bul. No. 140, California Expt. Sta., 1902.

[b] C. H. Shinn. Alkali Reclamation at Tulare Substation. Report of California Expt. Sta. for 1898–1901.

In 1889, 3 tons of gypsum were applied to the entire 20 acres. Since 1891, 100 tons of gypsum have been used, making an average of 7.7 tons per acre for thirteen years. Allowing for impurities, however, an average of not more than 5.39 tons per acre were applied each year. Some of the land still remained in bad condition in 1902.

The plans for the reclamation of alkali lands recommended by Loughridge[a] in the report for 1901–1903, are—

(1) The application of gypsum if black alkali be present, in order to insure the percolation of the irrigation water. The gypsum should be applied in sufficient quantities to neutralize the carbonate and convert it into the sulphate.

(2) If possible, the establishment of a system of subdrainage with tiles placed at a depth of 4 to 7 feet, according to the character of the soil and the crops intended to be grown.

(3) The application of sufficient water by flooding to percolate down through the soil to the drains and thus carry off the soluble alkali salts.

(4) Should drainage of the land not be feasible, then the alkali should be leached down to a depth of 6 feet by flooding the field with water. Care should be taken to keep the surface soil loose to a depth of at least 3 inches, in order to prevent the subsequent rise of the water and the return of the alkali to the surface.

Hilgard, with Weber,[b] and later with Jaffa,[c] studied the effect of carbon dioxide on soil solutions and drainage waters. From long observations Hilgard was impressed by the very great frequency of the occurrence of gypsum in alkali waters and soil leachings, even when considerable quantities of soluble alkaline carbonates were present and when, a priori, the precipitation of practically all of the calcium in the gypsum as insoluble calcium carbonate might be expected.

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[a] R. H. Loughridge. Annual Report, California Expt. Sta., 1901–1903.

[b] E. W. Hilgard and A. H. Weber. On the Mutual Reaction of Carbonates, Sulphates, and Chlorides of the Alkaline Earths and Alkalies. Proceedings of the Society for the Promotion of Agricultural Science, 1888.

[c] E. W. Hilgard and M. E. Jaffa. Further Experiments on the Reaction Between Alkaline Sulphates, Calcic Carbonates, and Free Carbonic Acid. Proceedings of the Society for the Promotion of Agricultural Science, 1890.

Solutions containing gypsum, or in contact with it, are always alkaline, but on being evaporated to dryness or to relatively high concentration this alkalinity is diminished and a greater or less amount of calcium is precipitated as ordinary carbonate.

Considering the origin of these solutions, Hilgard is led to the view that the unlooked-for phenomena presented are due to the presence of an excess of carbonic acid in the waters or soil leachings, and points out the great probability of its presence. This was tested by passing carbon dioxide for periods of time varying from ten minutes to two hours into solutions of alkali sulphates and chlorides, at the ordinary room temperature, in which precipitated calcium carbonate was suspended. Taking care to avoid the first masking of the reaction, which sometimes occurred from the excess of carbon dioxide, in all cases the solutions were found to have become alkaline, and on the addition of alcohol to the solution a precipitate was thrown down in which gypsum and calcium carbonate could both be readily recognized.

Together with Weber, he then undertook some quantitative measurements. Solutions containing from 0.25 gram to 2 grams of potassium sulphate per liter were made up. In these solutions calcium carbonate was suspended, and the solutions were agitated while passing in carbon dioxide for forty minutes. The solutions were kept at 18° C. during the experiment, and a little litmus was added. At first the solution would redden, owing to the action of the carbonic acid on the litmus, but in ten minutes it would become blue, the color intensifying as the reaction progressed. At the end aliquot proportions were filtered and tested as follows:

(1) The total alkalinity was determined by titrating with normal sulphuric acid. (Alkalinity=number of cubic centimeters of the normal acid required.)

(2) The portion was completely evaporated and dried at 110°, then leached and the alkalinity of the leachings determined by titration with normal sulphuric acid.

(3) To another portion alcohol was added to make about a 60 per cent alcohol solution, whereupon gelatinous precipitate settled, which, after standing twelve hours, separated into easily recognized crystals of gypsum and calcium carbonate.

From the figures obtained it was concluded that at a point somewhere between the solutions containing one-half gram and 1 gram per liter of potassium sulphate the reaction was complete as to the replacement of the sulphion by the CO_3 ion, but beyond this point the replacement was less complete and the relative amount of the replacement was a regular function of the initial concentration and, further, that the solution did not necessarily become saturated with respect to acid calcium carbonate, nor the composition of the residue affect the alkalinity.

COLORADO.

O'Brine[a] gives an analysis of samples of alkali from near Fort Collins that was composed largely of sodium chloride and sulphate. To counteract alkali in small quantities deep tillage is recommended. When alkali is present in large quantities underdrains are advised. The roots of plants on underdrained land will go deeper for the necessary moisture, and a small quantity of water applied at the proper time will carry off the alkali from the surface soil. The experiment of Professor Cassidy on the college farm is cited. Drain tiles were laid 30 feet apart and 3½ feet deep, discharging into an open ditch. Before the land was drained the ground was covered with a white incrustation of alkali, but none was to be seen after the installation of the underdrains. Drainage is strongly urged for soils that are irrigated with water containing any considerable quantity of alkali salts.

In 1898 Headden[b] undertook the study of the relation of alkali to the growing of sugar beets. The soil selected varied from a loam containing some gravel and having a somewhat calcareous clay subsoil to a fine alluvium, all of the soil to a depth of 5½ feet being retentive of water. Parts of the plat were covered with incrustations of salts one-half-inch thick after irrigation. The conclusions reached are as follows:

Beet seed will germinate freely in soil containing as much as 0.10 per cent of sodic carbonate, but the young plants are injured by as much as 0.05 per cent, and it is doubtful if any of them can survive when there is as much as 0.10 per cent of this salt in the soil. Sodic sulphate affects the germination to a much less degree, even when it is equal to 0.80 per cent of the air-dried soil, but it is injurious when present in larger quantities. When both salts, sodic carbonate and sodic sulphate, are present in equal quantities the action of the carbonate is only slightly or not at all mitigated. Magnesic sulphate retards but does not prevent germination when present in quantities equal to 1 per cent. Sodic salts hasten germination by from thirty-six to forty-eight hours. The effect of the alkali is of itself not detrimental to the sugar content of the beet. The presence of alkali increases the weight of the leaves very slightly and has no marked influence on the date of maturing.

In a subsequent paper Headden[c] announced the further results along this line of investigation. It was found that the application of straw as well as of manure improved the condition of the ground and perceptibly mitigated the effects of the alkali. The force of capillarity caused water to rise 45 inches as a maximum, the surface of the soil being protected from wind and sun.

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[a] Soils and Alkali. By D. O'Brine, Bul. No. 9, Colorado Expt. Sta., 1889.

[b] A Soil Study: Part I. By W. P. Headden. Bul. No. 46, Colorado Expt. Sta., 1898.

[c] A Soil Study: Part II. By W. P. Headden. Bul. No. 58, Colorado Expt. Sta., 1900.

Headden[a] states that alkali is much less injurious in itself than the conditions which admit of its formation. In the incrustations formed upon the soil are sodic, magnesic, and calcic sulphates, and sodic chloride. This is the order of importance in the incrustations, but not in the soil, the sodic and magnesic sulphates forming about 80 per cent of the total salts brought to the surface. The aggregate quantity of soluble salts per acre, whose movement is affected by the water falling as rain or applied to the surface in irrigating and also by its evaporation, is large. The application of water in irrigating may carry the soluble salts so deep into the soil that a long time may be required for them to come to the surface again. Analyses are cited to show how very different the percentages of the various salts are in the alkali and in that portion of the soil which is soluble in water. The water-soluble portion of the soil contains a relatively small quantity of sodic sulphate, while the alkali contains a large quantity. The sodic sulphate, together with the magnesic sulphate, is concentrated in the alkali. The incrustations are formed by the evaporation of water from the surface of the soil which, owing to the deportment of these salts toward capillary action and the chemical instability of the hydrated salts themselves, effects their separation from the soil solutions. Efflorescent alkalies are quite different from the residue left by evaporating bodies, such residues seeming to be intermediate between those obtained by evaporating ground waters to dryness and those brought to the surface by capillarity and appearing as efflorescenses on the ground.

In a later bulletin Headden[b] deals with the subject of the ground water. He states that for the eastern slope of the Rocky Mountains "the question of alkali resolves itself into one of drainage and beyond this there is no alkali question." The presence of alkali salts and whatever injurious effects they may have produced is due principally, if not wholly, to the lack of drainage, which in many instances has been made more apparent and its effect greatly augmented by overirrigation. He further states that he has seen no occurrence of alkalies in the States of the eastern slope where their accumulation was not due to the lack of drainage, the alkalies accumulating in depressions with no outlet, which serve as collecting places for the water draining from the higher ground, or along water courses where the lowness of the land and character of the vegetation prevent proper drainage.

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[a] A Soil Study: Part III. By W. P. Headden. Bul. No. 65, Colorado Expt. Sta., 1901.

[b] A Soil Study: Part IV. By W. P. Headden. Bul. No. 72, Colorado Expt. Sta., 1902.

IDAHO.

Burd,[a] preliminary to a detailed study of the alkali districts of Idaho, discussed in a general way the effects of alkali, its composition, formation, and methods of accumulation in the soils, as well as various methods for the reclamation of lands already strongly impregnated with alkali salts.

Burd,[b] in a subsequent bulletin, describes the results of studies of the soils and alkali conditions in the Payette Valley, situated in the western part of the State. The region studied comprises the basin of the Payette River for the last part of its course, just before its confluence with the Snake River. About 50,000 acres are under existing canals, but not all of this land is cultivated. The greater part of the agricultural land of the valley lies south of the river. The so-called bench lands lying between the river and surrounding hills form one of the principal features of the topography.

Usually the benches are separated from the river by areas of level bottom land. Prior to the opening of the large high-lying ditches some farming was carried on in the lower bottom lands, but later much of the river bottoms was abandoned because of the accumulation of alkali and seepage waters. The soils of the valley as a rule are alluvial silty loams, light in texture and color. On account of the fineness of texture most of the soils do not drain readily. Tables are given showing the results of analyses of eight samples of well water and more than one hundred samples of soils.

In the valley the wide distribution of dark spots and stains on the soils indicates that black alkali is the predominating variety. In the analyses it was found that black alkali is present in greater quantities than the other constituents. In lands whose fertility has been the most affected the carbonate equivalent is frequently as great as 0.3 to 0.5 per cent, which of course precludes any attempt at cultivation. Virgin and cultivated soils, the latter growing fine crops, are shown by the analyses to contain on the average an equivalent of 0.10 per cent or more of sodium carbonate. In general sodium chloride averages less than sodium carbonate and in good growing upland soils amounts to 0.03 per cent or less.

The soluble sulphates frequently run high—from 0.20 to 0.40 per cent—in the moist lands, but in lands growing good crops are present in small quantities as compared with the other salts.

The virgin soils as a rule contain smaller quantities of soluble salts in the surface foot than in succeeding feet. The quantities in the surface foot are usually below the limit of tolerance for nearly all crops, so that while most of the land produces well at the start its ultimate state depends on whether the local conditions are favorable to an increase or decrease of the salts near the surface. In conclusion, Burd states that the quantity of alkali in the valley is quite large and furnishes a serious obstacle to the successful farming of large areas. Irrigation has resulted in improving certain favorably situated soils by working the salts to greater depths, or into the drainage, or onto neighboring lands. But on low-lying lands, or wherever the natural drainage is poor, accumulation of alkali has been brought about. The accumulations consist largely of sodium carbonate. Unfortunately, the use of gypsum is impracticable, because the quantity of resulting sodium sulphate, in addition to the sulphate and chloride already present, would in most cases still be far above the toxic limit for the crops grown. In even the most favorably situated soils the alkali content is quite high, and unless water is sparingly used or the underdrainage is exceptionally good the tendency of the salts to come to the surface is soon observed. The topography of the bench lands is admirably suited to artificial underdrainage, which would probably solve the alkali problem for lands so situated. It is difficult to see how the low-lying river lands could be successfully underdrained, and for the present at least such lands should be avoided or chosen with great care when intended for agricultural purposes.

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[a] J. S. Burd. Alkali and the Treatment of Alkali Lands. Bul. No. 44, Idaho Expt. Sta., 1904.

[b] J. S. Burd. Alkali Conditions in the Payette Valley. Bul. No. 51, Idaho Expt. Sta., 1905.

MONTANA.

Traphagen,[a] in an article on the alkali soils of Montana, discusses the origin of alkali. Near Billings, in the Yellowstone Valley, it was found that the decomposition of the Fort Benton shales furnishes the alkali, which consists largely of sulphates. Numerous cases are cited to show that the rise of the ground water resulted in the swamping of deep-rooted crops and by evaporation in the accumulation of alkali at or near the surface. Many analyses of soils near Billings showed the alkali salts to consist largely of sodium sulphate. Alfalfa is recommended as the ideal crop for alkali lands. Judicious surface flooding is regarded as beneficial. Irrigation should be practiced with caution, and where the farmer can afford it the alkali lands should be underdrained.

Traphagen,[b] in a later bulletin, discusses the origin of alkali salts as found in soils of arid and semiarid districts. The example of a soil derived from the decomposition of granite is given to show the manner in which the various salts are formed. Whether the soluble salts formed by the decomposition of the granite will accumulate depends entirely upon the subsequent history of the soluble portion of the rock. With an excess of water, as in regions with a humid climate, the soluble salts will be removed nearly as fast as formed, but in a district of scant rainfall, where but a small portion of the soluble salts is removed, they will accumulate to an alarming extent where conditions are favorable to this action. The rise of alkali is discussed, as well as the distinction between white and black alkali. The remedies for the rise of alkali are considered under the three heads of prevention, amelioration, and eradication. Prevention resolves itself into two parts. First, avoid as far as possible, by using small amounts of water, the solution of objectionable matters; second, reduce surface evaporation to a minimum. Under the head of amelioration he recommends the plowing under of straw or similar material as soon as possible after irrigation and the planting of such crops as can withstand considerable alkali. The eradication of the alkali can only be brought about by underdrainage. The importance of this method is discussed, and quotations from publications of the Bureau of Soils are introduced to emphasize the desirability of this method.

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[a] The Alkali Soils of Montana. By F. W. Traphagen. Bul. No. 18, Montana Expt. Sta., 1898.

[b] The Alkali Soils of Montana. By F. W. Traphagen. Bul. No. 54, Montana Expt. Sta., 1904.

A table of analyses of 358 samples of alkali soils from different parts of the State is given, showing the content of chloride, sodium sulphate, and sodium carbonate. Traphagen also reports the results of pot experiments with alfalfa, oats, wheat, barley, and timothy in soils containing varying quantities of alkali salts. Five plates are included, showing graphically the results of the pot experiments. The following summary of general results of the experiments is given:

"The presence of magnesium sulphate—epsom salt—in quantity up to 1 per cent has apparently no ill effect upon the growth of alfalfa. The limiting quantity of sodium sulphate—Glauber's salt—for alfalfa seems to be about seven-tenths of 1 per cent. With a mixture of two-thirds sodium sulphate and one-third magnesium sulphate, which represents very closely the composition of Montana alkali, the limiting quantity appears to be about the same as with sodium sulphate alone."

The danger limit for the Montana type of alkali for oats, wheat, barley, and timothy is given as above 1 per cent.

NEW MEXICO.

Goss[a] discusses the value of Rio Grande water for the purpose of irrigation. He states that owing to the presence of gypsum in the water alkali deposited from the Rio Grande must be of the white variety. Daily samples of water were taken from June 1 to November 1, usually for a period of two weeks. These samples were mixed, and at the end of the period an analysis was made of the average sample. The samples were found to vary greatly in composition, the range of water soluble material after evaporation being in the ratio of 1 to 7. As the alkali deposited from the river water is white, the best method for its removal is by means of drains and the use of water, thus washing it out of the land. If possible the river water should not be used for irrigating immediately following a rise due to heavy rains coming after a protracted dry period, as it then contains more alkali. As compared with other rivers, the Rio Grande ranks high for irrigating purposes.

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[a] The Value of Rio Grande Water for the Purpose of Irrigation. By A. Goss. Bul. No. 12, New Mexico Expt. Sta., 1893.

Goss and Griffen[a] describe the alkali conditions in the Rio Grande and Animas valleys. Analyses of soils from the Rio Grande Valley show the alkali to be of the white variety, consisting largely of sulphates and chlorides of soda, with some calcium sulphate, calcium chloride, magnesium sulphate, magnesium chloride, and potassium sulphate.

In the Rio Grande Valley are many low basins near the foothills that receive the drainage from higher lands. This water soon evaporates, and these places have become notoriously bad alkali spots. In the Animas Valley considerable low-lying land is being swamped by the rise of the water table due to excessive irrigation and leaky ditches. In the Animas Valley 0.23 per cent of sodium carbonate in the surface soil was sufficient to prevent entirely the germination of the seeds of ordinary farm crops. Washing out the alkali is urged as the best and most permanent remedy, but it is pointed out that the expense is considerable and that generally the alkali occurs in low-lying lands that are difficult to drain.

Gypsum was applied to soils containing white alkali in the Rio Grande Valley, but the result was purely negative. In Las Animas Valley are patches of soil with no vegetation except greasewood, or "chico," and saltbush (Atriplex). In these patches the soil though sandy is hard and compact. A black incrustation was found in some places. Analysis of a surface crust showed 0.23 per cent of sodium carbonate. Chemical examination of the "chico" showed it to contain large quantities of potash and soda, and plainly showed it to be the immediate source of the black alkali. The roots of the plants extend deep into the ground and for long distances away, and pump up with the soil moisture the material from which the black alkali is formed. This collects in the leaves and stems, and when they drop and decay an accumulation of black alkali results immediately under the bush. Experiments were tried with this soil by placing it in boxes and treating it with gypsum. It was found that the injurious effects were overcome, and sugar-beet seed germinated freely. Tests were then made on alkali spots, and favorable results followed, as seeds sprouted and made some growth, and the physical condition of the soil was improved. The surface crust was then analyzed, and it was found that the carbonate had been changed to white alkali.

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[a] Alkali in the Rio Grande and Animas Valleys. By A. Goss and H. H. Griffen. Bul. No. 22, New Mexico Expt. Sta., 1897.

From experiments at Aztec and Mesilla Park rye was found to be the best of all the cereals in resisting the effects of alkali. In Las Animas Valley the opinion is expressed that the alkali comes chiefly from the highlands bordering the valley.

Tinsley,[a] in a very comprehensive bulletin on alkali, has summarized the work of the different experiment stations and pointed out the alkali problems in New Mexico. Two principal sources from which the accumulation of alkali may be expected are given. The first of these is the accumulation and evaporation of water in low places. The second and the principal cause is the accumulation of sufficient water in the soil to raise the water table high enough for capillarity to supply the water lost by evaporation at the surface.

For the prevention of the accumulation of alkali there are two fundamental principles to be observed. The first is to keep the water table below the point where capillarity can bring up large amounts of water; the second is to reduce surface evaporation to the very least possible amount. The water table may be kept down by open or covered drains. A depth of 3 feet is recommended, and any less depth is regarded as unsafe. To prevent evaporation, surface cultivation and mulching with manure, straw, and other similar materials are advised, and the effect of a covering of vegetation in decreasing evaporation is pointed out. The relation of manure to alkali is discussed. It is pointed out that there seems no possible chemical reaction by which the manure can change the composition of the alkali and render it less injurious, but its use often results in marked benefit. The beneficial action may be due partly to the fact that it tends to loosen the surface soil and partly to the fact that it may act as a stimulant, especially to young plants, and enable them by their greater vigor to resist the action of alkali. For the removal of alkali from the soil three methods are discussed, namely, removing the surface soil, growing resistant plants, and leaching and underdrainage.

In a subsequent bulletin Tinsley[b] published the results of an experiment in drainage and flooding for the removal of alkali. A 20-acre tract was selected in the Hondo bottoms east of Roswell. The soil is rather heavy, much of it being a heavy clay loam. The greater part of the tract was covered with bunch grass—locally called "salt grass"—and part of it with true salt grass. On much of the land the water table was so near the surface that cultivation was impracticable.

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[a] Alkali. By J. D. Tinsley. Bul. No. 42, New Mexico Expt. Sta., 1902.

[b] Drainage and Flooding for the Removal of Alkali. By J. D. Tinsley. Bul. No. 43, New Mexico Expt. Sta., 1902.

The alkali was nearly all of the white variety, consisting of sodium sulphate, magnesium sulphate, calcium sulphate, and sodium chloride, with small quantities of sodium bicarbonate or carbonate. The drainage system consisted of a main central drain 610 feet long, part being an open ditch, part consisting of 8-inch tile, and the upper 240 feet of 6-inch tile. On the east of the central drain were 12 lateral drains. Some of these were laid 30 feet apart and consisted of 3-inch tile between 2 and 3½ feet deep. Other laterals were 40 feet, 60 feet, and 100 feet apart and consisted of 4 and 5 inch tile. The work of installation was completed May 1, 1900. In July, 1900, flooding was commenced. The drains lowered the water table to the depth of the tiles, and in 1901 much of the alkali had been washed from the first and second foot of the soil. Because borders were not adequate to hold the water on the land and because the surface was covered with a hard and compact sod, the leaching away of the alkali did not progress so rapidly as expected.

As a result of the experiment Tinsley concludes that where the water table is within 6 inches or less of the surface the amount of alkali is low. The maximum effect of capillarity in the Hondo meadows soil is found where the water table is about 2 feet below the surface of the ground. Ten floodings removed about one-seventh of the total alkali from the first 2 feet of soil and carried a large proportion of that formerly in the first foot down into the second. He states that combined open and tile drains will cost from $20 to $30 an acre.

Goss[a] gives the results of ash analyses of some New Mexican plants. All the plants of the Territory seem to average higher in ash than the plants of the rainfall district. This is probably due to the more concentrated solutions of mineral matter present in the soils in which they grow. In regard to the mineral contents of plants growing on alkali soils there does not seem to be much uniformity. For example, salt grass and bunch grass, while containing about an average quantity of ash, are much lower in soda, potash, lime, magnesia, and the other elements usually found in alkali than many of the plants growing on the soils containing much less alkali. On the other hand, the sea-blite and chico bush, both alkali-loving plants, are very high in soda and some of the other elements found in alkali. Goss concludes that the species of the plant has perhaps more to do with its mineral composition than the environment under which it grew.

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[a] Ash Analyses of some New Mexican Plants. By A. Goss. Bul. No. 44, New Mexico Expt. Sta., 1903.

WASHINGTON.

In 1901 Heileman[a] described the alkali conditions in the Kittitas and Yakima valleys. In the Kittitas Valley it was shown that while all the land contained some alkali, that which was uncultivated and unirrigated showed the least. It was also shown that land irrigated with the least quantity of water showed less surface alkali than land lying adjacent to irrigating canals. In all cases where unlimited or excessive quantities of water were obtainable for irrigation there were found tracts which were entirely unfit for cultivation. It was found that the natural drainage of the land was unfavorable for the rapid elimination of seepage water or alkali-charged water into the river. Natural drainage in many places is hindered by a layer of calcareous hardpan, which checks the drainage and favors the retention of the alkali above it. The source of the alkali seems to be the soil in the valley, with accumulation and concentration in the lower basinlike depressions. The alkali consists mainly of carbonates, with sulphates and chlorides present in limited quantities. The use of land plaster or gypsum is recommended to overcome the injurious effects of the black alkali.

An experiment in the reclamation of alkali land is also described. This was on Mr. Tjossem's farm in the Ellensburg district. A mole plow, so constructed that a wooden box could be drawn after it through the soil, was used and the field satisfactorily drained and then flooded. The results of this experiment were excellent, good crops being raised on land that before had supported only the alkali-resistant salt grass.

In the Yakima Valley both carbonates and sulphates were found and often sodium chloride. The greater part of the alkali is sodium sulphate. The soil does not show a high percentage of lime or magnesium carbonates.

WYOMING.

Buffum,[b] in speaking of the effects of alkali, states that the greatest injury to plants is due to the alkali interfering with the life function of absorption, and probably also of assimilation, in the plant economy. If present in small quantities, the growth is merely retarded, while if the soil contains larger quantities of salts, the growth is entirely stopped or the plant destroyed.

A series of tests were made to determine the effect of alkali on the germination and early growth of various plants. A portion of soil was washed until it showed no traces of sulphates or chlorides. Then different percentages of alkali were incorporated with the soil and enough water added so that in each case there was 25 per cent of water in the soil when the seeds were planted. It was found that even a small percentage of alkali retarded germination, and the greater the quantity, up to the amount necessary entirely to prevent development of the germ, the greater the time necessary for the seeds to germinate. The experiments demonstrated that alkali has a physiological effect on the vitality of the seed and plant. The results in tabular form showed that some crops can withstand greater quantities of alkali than others. Rye was found to grow upon soil containing comparatively large quantities of alkali. Wheat comes next in point of resistance, then barley, and lastly oats. Turnips were found quite susceptible to alkali, while alfalfa would germinate in soils containing moderate quantities of alkali. The reason why alkali retards or prevents development was not satisfactorily determined. It was found that the water did not readily enter the seed when the soil contained from 5 to 15 per cent of alkali, and the seed swelled slowly. The outer seed coat on wheat and rye seemed to swell faster than the starch inside, leaving the kernel loose and wrinkled. No apparent change could be detected in the germ, even when examined under a high-power microscope, and it would seem that the physiological effect produced by alkali is not necessarily fatal to the life of the germ.

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[a] Alkali and Alkali Soils. By W. H. Heileman. Bul. No. 49, Washington Expt. Sta., 1901.

[b] Alkali. By B. C. Buffum. Bul. No. 29, Wyoming Expt. Sta., 1896.

The reclamation of alkali land was tried upon one of the station farms. A series of open ditches were dug around and upon the Sheridan farm. They were so constructed that the water in times of heavy rainfall or when the land was irrigated would be drained away to a depth of 2 feet below the surface. Reports one year later showed marked improvement, and it was believed the land would be entirely reclaimed.

In a subsequent bulletin Slosson[a] discussed the character of alkali found in Wyoming. Almost all the alkali in the State was found to consist of three salts—sodium sulphate, magnesium sulphate, and sodium chloride—in varying proportions. Sodium carbonate is very rare. The alkali salts are noted as occurring in large beds of single salts, often very pure. Near Laramie are beds of sodium sulphate, near Rock Creek beds of magnesium sulphate, and near Green River beds of sodium carbonate, many acres in extent and several feet in thickness.

The origin of the "alkali lakes" is discussed. The origin of the salts, it is stated, need not be considered if it is remembered that the kinds of salts deposited from a solution depend upon the proportions of the different salts, the temperature of the solution, and the degree of concentration, and need not be the same as the salts dissolved. Slosson states it is not impossible that a consideration of the simpler reactions may throw light on the probable way in which pure salt deposits have been formed. Starting with a solution, such as natural waters, containing the bases calcium, magnesium, and sodium and the acids carbonic, sulphuric, and hydrochloric, the most insoluble compound would be first precipitated. This is calcium carbonate, or a mixture of calcium and magnesium carbonates, forming beds of limestone or dolomite. The calcium sulphate would next be deposited in the form of gypsum, and it is mentioned that beds of gypsum of great thickness exist in many parts of the State, as at Red Buttes. In the Laramie Plains gypsum was found at intervals in boring to a depth of 1,000 feet. If sodium was originally extracted from the rocks in the form of carbonate, the absence of this salt in most of the State could be accounted for by the reaction between sodium carbonate and calcium sulphate to form sodium sulphate and limestone.

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[a] Alkali Studies: II. By E. E. Slosson and B. C. Buffum. Bul. No. 39, Wyoming Expt. Sta., 1898.

If both the calcium and the carbonic acid were completely precipitated, there would be left as possible compounds magnesium chloride and magnesium sulphate and sodium chloride and sodium sulphate. Of these, magnesium chloride is by far the most soluble at ordinary temperature and would therefore be the last salt deposited in and the first washed out from an alkali bed. In the waters of the State the sulphates are in large excess over the chlorides, so magnesium chloride may be regarded as practically absent, and the salts formed would only be magnesium sulphate, sodium sulphate, and sodium chloride. Analyses show that all alkali of the State consists of these three salts in varying proportions. There are beds of the first two, but so far no deposits of sodium chloride have been found.

A study was made of the absorption of water from alkali solutions by seeds. Experiments were carried on with wheat seed, and it was found that the absorption of water was not influenced by the kind of alkali nor the strength of the solution, but purely by osmotic pressure. Solutions of sugar, sodium sulphate, magnesium sulphate, and sodium chloride were so made as to have the same osmotic pressure, and it was found that wheat absorbed just about the same quantity from each of these in the same length of time. Beans absorbed the same quantity of water, whether it was pure or a saturated solution of common salt. The dissolved salt passed into the bean apparently as readily as water and destroyed the power of germination. With the exception of sodium carbonate it was not found that the salts mentioned exerted any poisonous influence on the wheat, as it germinated readily when removed from the alkali solution and put under favorable conditions. The absorption of water is retarded and diminished by the pressure of salts in the water, but not prevented. This is due to the fact that the seed allows the salt to pass into it, though not so readily as the water. The volume of the swelled seed and the amount of salt they contained were determined, and it appeared that in strong solutions enough salt was absorbed to make the solution inside the seed nearly the same strength as the outside. In this way the resistance to absorption of water due to osmotic pressure is diminished. The same means of obtaining water from a strong salt solution is probably used by such plants as the salt sage, which contains a large amount of mineral salts. This has the double advantage of aiding the plant to drain water from the soil and better to keep what water it has, because the salts dissolved in the sap lessen the evaporation.

Knight,[a] in discussing the alkali lakes and deposits of Wyoming, states that in addition to large areas of soils containing alkali, where there are exposures of clays, shales, and sandstone, even though soils do not exist, there are also accumulations of the various salts. These come from the rocks in place, there being sufficient moisture to bring the alkali to the surface. In such cases the source of the salts is traceable to the original sedimentary rocks. All of the formations from the Triassic up to the Tertiary, inclusive, contain more or less of these various compounds. In some localities the quantity of alkali stored in clays and shales is enormous. In the Red Desert there are clay beds of a dull-red color. Only a few inches below the surface the alkali often amounts to 30 or 40 per cent of the mass. In addition, many springs contain unusual quantities of salts, one being mentioned that contains 10 per cent of sodium carbonate.

The point is brought out that, while all deposits of alkali occur in undrained depressions, the depressions surrounded by Paleozoic and Mesozoic rocks contain only very slight quantities of alkali. This may be explained by the fact that the territory draining into the depressions contains little or no alkali, or else the underground drainage may be sufficient to permit the salts to be drained away.

The granite soils were examined and found to be remarkably free from alkali. It was found that the feldspars were not undergoing rapid decay. Weathering of the granites along the mountain ranges in arid regions results in the separation of the quartz and perhaps the oxidation of the mica and hornblende, and consequently but little soil is being formed, and all of the salts appear to be washed into the streams and in no instance to be stored upon the land. Since nearly all of the granites of this State have orthoclase as the dominant feldspar, the alkali produced should be potassium, but all of the deposits are almost free from any of the potassium salts.

The older series of rocks were examined, including the Algonkian, Paleozoic, Cambrian, Ordovician, Carboniferous, and Permian, but no alkali was found associated with any of these. Even in localities where these rocks were comparatively level and where natural conditions favored the accumulation of various salts none was found.

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[a] Alkali Lakes and Deposits. By W. C. Knight and E. E. Slosson. Bul. No. 49, Wyoming Expt. Sta., 1901.

Analyses of soils derived from the more recent geological formations contain many times as much alkali as those derived from the older rocks, and the waters flowing through them contain vastly more salts. Knight states that primarily the alkali has been produced by the decomposition of the various rocks containing these elements. These salts appear to have been formed extensively during the Mesozoic and Cenozoic eras, but in place of being stored in deposits were carried down with the sediments. Later, through mountain-making agencies, these formations were brought to the surface and through weathering have been converted into soil. The salts have remained in the soils so formed, since there has not been sufficient water to leach them out. The decomposition of the rocks is still in progress, and from this source and the stores already accumulated in the soils the deposits of alkali have been formed and are being increased.

There are hundreds of places in Wyoming where sodium salts are being accumulated, but as a rule they do not form beds of much importance. The deposits vary in size from a few acres to 100 acres or more and in thickness from a few inches to 10 or possibly 15 feet. The salts are always found resting upon a muddy bed, which is usually very salt. The mud varies in color from almost black to bluish and contains many crystals of sodium sulphate. When it is removed from the bed it has a strong odor of sulphuretted hydrogen and the odor often resembles that rising from dissolving sodium hyposulphate This mud always contains quite a high percentage of the salts found in the deposits.

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SOIL AND ALKALI SURVEYS IN IRRIGATED DISTRICTS.

In 1899 the Bureau (then the Division) of Soils undertook the study of soil and alkali conditions in the western irrigated districts. The results of this work have been published in the Field Operations of the Bureau of Soils. Inasmuch as the various reports describe in considerable detail the exact soil and alkali conditions in a great number of districts located in many of the arid States and Territories, and since they fully discuss the individual alkali problems of each area, it is thought this material assembled in one paper will be of great value to those interested in the subject of alkali investigations.

PECOS VALLEY, NEW MEXICO.

This area was surveyed in 1899 by Thomas H. Means and Frank D. Gardner.

The Pecos Valley is situated in the eastern part of the Territory of New Mexico and extends in a north and south direction along each side of the river bearing the same name. Its climatic conditions are characterized by a mild temperature, low relative humidity, abundant sunshine, and low rainfall. The mean rainfall is approximately 15 inches per annum and is not sufficient to produce more than a meager growth of vegetation. Irrigation is necessary, therefore, to carry on agricultural operations successfully. The soils of the valley are for the most part sands or sandy loams, gypsum, and conglomerate or gravel.

Extensive irrigation did not begin in this region until 1889, and for a few years following that date the region was extensively boomed. Large systems of irrigation canals and reservoirs were built at a cost of several millions of dollars. The soils before being placed under irrigation were almost always comparatively free from alkali, rarely containing more than 0.25 per cent of total soluble salts, and usually an amount considerably below this. After irrigation had been carried on for a few years, alkali began to make its appearance in certain places in sufficient quantities to be harmful to plants, and it was largely as a result of these conditions that the soil and alkali survey was made there in 1899. This work brought out the fact that the

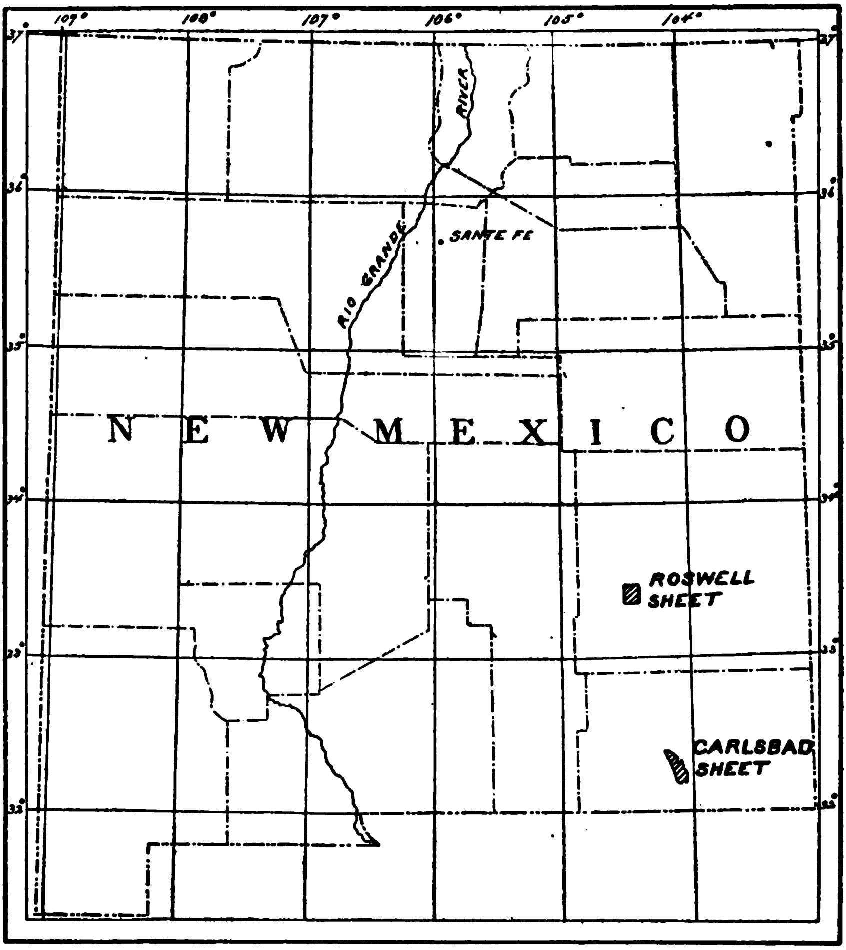

FIG. 1.—Sketch map showing location of areas in which alkali has been studied in New Mexico.

water supply for the upper part of the valley, especially that which was secured from the North and South Spring River and the artesian waters, which evidently rise from the same source, was very good, containing on an average about 75 parts of soluble salts per 100,000 parts of water. Of those salts about two-thirds were comprised of sulphate and carbonate of lime, which, as the water evaporated and the solution became more concentrated, crystallized out before a sufficient concentration was reached to be injurious to most plants. Farther down in the valley, however, where the water was taken directly from the Pecos River, it contained a higher percentage of salts, the percentage increasing as the distance down the valley increased. The water at Hagerman was found to contain 200 parts, at Carlsbad 240, at Florence 282, at Red Bluffs 316, and at Barstow, near Pecos City, 420 parts, while below Barstow the water from the river was found to contain 526 parts of salts per 100,000 of water, or a concentration which in itself was almost sufficient to kill plants.

By the use of irrigation water containing such a large quantity of alkali the soil gradually increased in alkali content until areas where seepage waters had begun to accumulate contained sufficient alkali to prevent the growth of ordinary crops. The alkali, both in the water and the soil, is white, and from 50 to 80 per cent of it is made up of sulphates and carbonates of lime, magnesia, and soda. The presence of calcium sulphate explains why black alkali is not found in this region.

The gypsum land and the conglomerate are both sources of considerable trouble in irrigation. The gypsum soil washes very badly, and small laterals often cut down to a depth of 9 or 10 feet below the surface. The seepage from ditches is very large, not only causing a loss of water, but also accumulating in the soil to such an extent that it causes a rise of the alkali. In the case of the conglomerate soil there is little or no trouble from washing, but the soil contains such a large percentage of gravel that water passes through it very rapidly, and as a result many of the canals lose a great deal by leakage. It is also difficult to irrigate this soil, because the water passes down through it so rapidly that it is impossible to flood more than a very small area with a small stream of water. The rise of the ground water and the accumulation of alkali in various places in the valley is due to the bad condition of the water and the large amount of seepage from the canals and from overirrigated land.

SALT LAKE VALLEY, UTAH.

This soil survey was made in 1899 by Frank D. Gardner and John Stewart. The virgin soils usually contain considerable alkali. Where nature has provided good drainage the alkali moves downward upon the application of irrigation water and does no harm, but where drainage is poor it is necessary to provide artificial drains in order to reclaim alkali land.

The source of the alkali is the water of Great Salt Lake, which, within the memory of the older inhabitants, has covered much of the low-lying lands, or from the waters of its predecessor, Lake Bonneville, in the case of the more elevated lands.

The alkali is composed largely of chloride of soda, with a lesser amount of sulphate of soda and a small percentage of chlorides, sulphates, and carbonates of lime and magnesia. Sodium carbonate or black alkali is frequently present in very small quantities, and in many places occurs in sufficient quantity to be injurious to vegetation. Wherever present in such quantities, however, it is accompanied by white alkali also in sufficient amount to prevent the growth of crops.

The water supply is usually of good quality. That for the lands west of the Jordan River is mostly from Utah Lake, and that from the east is derived directly from the mountain streams. The source of Utah Lake water is also chiefly the mountain streams. Seepage water from adjacent irrigated land, together with evaporation from its surface, increases the salt content of the lake water, but not in sufficient degree to make the water harmful for irrigation purposes. The salts of the irrigation water are of the same kinds as those in the soil. The percentage of chlorides is slightly less, while the sulphates are correspondingly increased.

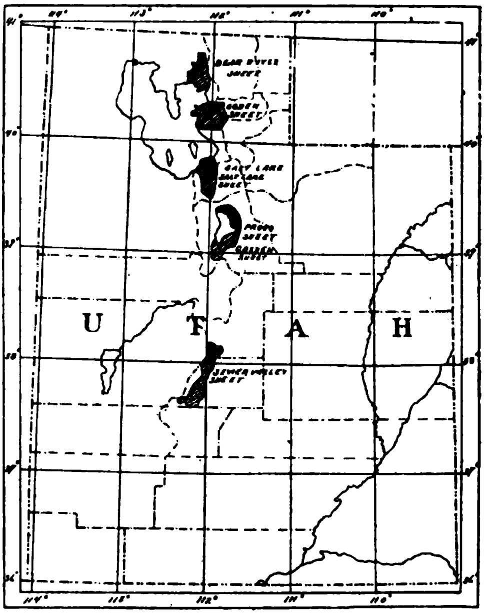

FIG. 2.—Sketch map showing location of areas in which alkali has been studied in Utah.

Overirrigation and leakage from canals are the sources of considerable trouble and have resulted in considerable damage to land. Such lands can best be redeemed by thorough underdrainage and flooding. The same method will be required for the reclamation of the low-lying and salty lands.

SANPETE, CACHE, AND UTAH COUNTIES, UTAH.

Means in 1899 made a rapid survey of the alkali soils of these counties with the following results:

Utah County lies directly around the fresh-water lake of the same name. The soils are the sediments of ancient Lake Bonneville, modified by weathering and inflowing streams. Irrigation water of excellent quantity is obtained from mountain streams. Parts of the country have been cultivated nearly forty years. When the valley was first settled land immediately adjacent to Utah Lake was wet and swampy. By irrigating the upland the wet land has greatly increased in area, but is still of value as grazing land. The principal damage is from seepage waters, but where the soil is heavy salts have accumulated at the surface in sufficient quantities seriously to damage the lowlands. Moderate quantities of salts are everywhere present in the soil, and through the agency of irrigation and seepage waters they have been concentrated in small areas.

Sanpete County is located in the central part of the State, and its farming lands lie in the valleys of Sanpete and Sevier rivers. These valleys are quite level and slope gradually toward the mountains. The irrigation water is not so good as in Utah County, and some of it is so bad that its use is attended with risk unless precautions are taken to prevent concentration in the soil.

Cache County lies in the north central part of the State. Irrigating water of excellent quality is taken directly from the tributaries of Bear River.

The soils of Cache and Utah counties are ancient lake sediments. The soils of Sanpete County were formed from materials brought down from adjacent mountains, but they are very similar to those of the other counties. The soils vary from light sand and small gravel to the heaviest and most tenacious clays.

In Utah and Cache counties both white and black alkali are present. Analyses of samples of black alkali crusts from Utah County show as much as 20 per cent of sodium carbonate and nearly 80 per cent of sodium chloride. Crusts of white alkali show large quantities of sodium sulphate as well as sodium chloride. Crusts from the shore of Utah Lake show sodium chloride as the prevailing salt, with 33 per cent of magnesium sulphate. In Cache County black alkali is limited to spots in the west central part of the valley and is always associated with the white alkali. A sample from a tule swamp shows 39 per cent of magnesium sulphate, 36 per cent of sodium sulphate, and 22 per cent of sodium chloride. A crust of black alkali showed on analysis 46 per cent of sodium sulphate, 41 per cent of sodium chloride, and 12 per cent of sodium carbonate.

In Sanpete County the alkali so far as examined was all white. The presence of gypsum in nearly all the soils and in the irrigation waters would lead one to expect this. Analyses of representative samples showed sodium sulphate as the principal salt, with considerable amounts of sodium chloride.

The reconnoissance in the three counties showed that the presence of alkali in the soils was due to defective natural drainage. The obvious remedy is artificial drainage. As tile-drains offer the most effective, and in the end the cheapest method of drainage, their use is recommended. On black alkali soils gypsum is recommended.

Means in 1899 made a reconnoissance in the Cache la Poudre Valley, Colorado, but as this valley was subsequently surveyed and the soils studied in detail by Holmes and Neill in 1904, it will not be considered further at this point.

WEBER COUNTY, UTAH.

Weber county was surveyed in 1900 by Frank D. Gardner and Charles A. Jensen. Irrigation in this district is more than half a century old, having been commenced soon after the Mormons settled at Salt Lake City in 1847. The climate, water, soils, and alkali are essentially the same as those of Salt Lake Valley.

Agriculture is usually of the intensive type. The farms are small, well cultivated, and devoted chiefly to the growing of sugar beets, fruits, and vegetables, especially tomatoes for canning.

The mean annual precipitation is about 14 inches, of which less than 4 inches occur during the growing season. In the adjacent mountains the precipitation is greater, and a considerable part of it occurs as snow, which on the higher peaks lingers through the greater part of the summer. The snow of the mountains is important in relation to irrigation, since it is the source of water exceptionally free from salts, and by its gradual melting prolongs the flow of water in the streams. The canals are usually owned by the proprietors of the lands which they supply with water.

The soils are usually sandy loams, with smaller areas of sands and loams. The low-lying land near the lake shore contains 3 to 10 per cent of salt in the first 6 feet of soil, and is usually bare of vegetation.

The water supply is excellent, and comes chiefly from Weber and Ogden rivers. The annual flow from those two streams is nearly half a million acre-feet. With storage facilities to impound all the water the acreage of irrigated land could be greatly extended. The salt content is low, and 70 per cent of it is in the form of bicarbonates.

Leakage from canals and the application of more water than necessary in the practice of irrigation has caused a rise of the ground-water table to a point which in many places is dangerously near the surface. The remedy for such conditions is greater care in irrigation and the prevention of seepage from the canals, thus economizing water. In many cases it will be necessary to resort to underdrainage in order to reclaim the lands.

The alkali of the district originates largely from the waters of Great Salt Lake, which in no very remote period has covered the greater portion of the irrigated lands of the district. About 64 per cent of the salts occur as chlorides, of which common salt is the usual form, 15 per cent as sulphates, and 11 per cent each of carbonates and bicarbonates. Interesting observations are made upon the variations in the composition of the alkali as found on the surface and at varying depths in the soil.

The use of underdrainage is emphasized as a means of reclamation and of preventing the destruction of lands under which the water table is constantly rising.

SEVIER VALLEY, UTAH.

The Sevier Valley area is located south of the center of Utah, in the counties of Sevier and Sanpete, and was surveyed by Frank D. Gardner and Charles A. Jensen. This portion of the valley extends in a general northeasterly direction from the town of Joseph at the south for a distance of 45 miles to the town of Gunnison. The average altitude of the valley is about 5,000 feet above sea level, while the adjacent mountains on each side rise from 2,000 to 6,000 feet higher.

The climate is arid, the mean annual rainfall being about 8½ inches, and for the year in which the survey was made the total rainfall was less than 2 inches. In general the valley is level, with a fall of about 7 feet per mile in the direction of the river, and about the same fall from the mountains toward the river, excepting near the foothills, where the inclination gradually becomes greater. The soils, usually light in texture, are formed largely from débris brought down from the adjacent mountains and, owing to their derivation, are very diversified in character. As a rule, the virgin soils of the valley are salty, owing to the fact that the salts are formed faster by the rapid disintegration of rocks than they are carried away by the scanty rainfall. In the upper part of the valley, about Joseph, Elsinore, and Monroe, the underlying gravel affords such excellent drainage that when the lands are placed under irrigation the salts are soon carried deep into the soil, where they do no harm and are eventually carried by the seepage waters into the river. Where natural drainage is poor it is difficult to bring these lands into cultivation without the aid of artificial drainage.

The native vegetation of the valley is distinctly arid in its character, and bears an intimate relation to the character of the soil and its salt content. The presence of salt grass and foxtail indicates plenty of moisture near the surface of the ground, and consequently free ground water not far below the surface, while the salt grass is especially indicative of a considerable amount of salts at the surface of the ground. The greasewood indicates dry land of medium texture containing considerable salt, and if the growth is heavy and excludes other plants it is a sure indication of 0.6 per cent or more of salt in the upper 5 feet of soil. If it is less flourishing and gives way partly to shadscale, the salt content will be found less than 0.6 per cent, while the shadscale alone indicates dry land containing less than 0.4 per cent. Rabbit bush does best on sandy soils that are comparatively free from alkali and seldom occurs under any other conditions. Sweet clover and foxtail in fields of alfalfa or grain which have a poor stand indicate wet land and probably from 0.2 to 0.4 per cent salts.

A few small canals were constructed in this valley prior to 1870, but most of them were built during the period from 1870 to 1880. The chief crops are alfalfa, oats, wheat, and barley. The irrigation water supply for the area is entirely inadequate to irrigate all the land unless storage is resorted to. By impounding all the waters from the close of one irrigation season to the beginning of the next enough water might be secured to irrigate all of the arable lands in the district. A reservoir with a capacity of 40,000 acre-feet has been constructed some distance above the district on Otter Creek, and on the Sanpete River between Manatee and Sterling there is a smaller reservoir which has been used for several years in irrigating land about Gunnison and Centerfield. Water being scarce, the farmers irrigate their fields by the furrow method, which consists in running parallel furrows 3 or 4 inches in depth at intervals of from 2 to 2½ feet down the slope of the field and turning the water into these furrows.

The water of all the canals taken from the river above Elsinore contains very little salt even at its lowest stage. Water taken from the river where irrigated lands are adjacent contains more salt, and the quantity increases as the distance downstream increases. Large springs at Richfield, Glenwood, and Redmond furnish water sufficient to irrigate considerable land. The spring waters, as a rule, contain slightly more salt than the water from the upper part of the river, but rarely carry more than 65 parts per 100,000, while artesian well waters have approximately the same composition as that from the springs. Water in surface wells, however, is usually very salty, and the mean salt content of waters from 13 wells was found to be 200 parts of salt per 100,000 of water, some of the wells running up as high as one-half of 1 per cent of salts. In the artesian and spring waters the bicarbonates constitute somewhat more than half, whereas in the seepage waters the chlorides exceed in amount those of all other salts combined.

The alkali consists of chlorides, sulphates, carbonates, and bicarbonates. The bicarbonates are always present in considerable abundance, while the carbonates are frequently present in small quantities only. The chlorides occur in greatest abundance in the lower part of the valley, their source being the beds of rock salt that are found in the mountains near Salina and Redmond. Throughout the district lime and magnesia carbonates are very plentiful, and are responsible for the large percentages of bicarbonates that are frequently present.

SALT RIVER VALLEY, ARIZONA.

Three areas were surveyed in 1900 by Thomas H. Means in the Salt River Valley. These covered areas around Tempe, Phoenix, and Buckeye. As the soil and alkali conditions varied somewhat in each area they may for convenience be discussed separately.

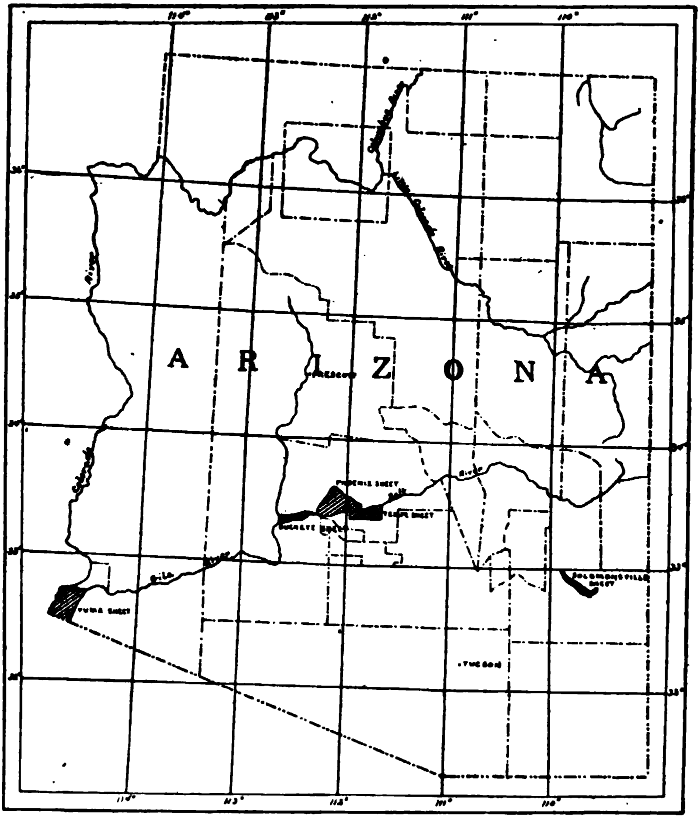

FIG. 3.—Sketch map showing location of areas in which alkali has been studied in Arizona.

The Tempe area comprises that part of Salt River Valley first settled by the modern irrigator. The soils of this district vary from a loam to gravelly loam and sand, all underlain by coarse, loose, incoherent gravel. Two terraces are included. Gravel from the lower levels of the upper terrace outcrops as a bluff that divides the two at a point southeast of Tempe. Nearly all the lower terrace was irrigated in prehistoric times and, at the time of its occupation by modern irrigators, was for the most part alkaline, although the water table was below the capillary reach of the surface. This alkali was no doubt due to a rising of the water table at the time of this prehistoric irrigation, and may have been accumulated at the time of the irrigation or after the abandonment of the lands, when, if the water table had been raised near the surface, evaporation would have been great. Upon cultivation by modern irrigators heavy flooding sweetened these lands to such an extent that the crops grown were unaffected by alkali. Alfalfa, which shaded the surface and prevented excessive evaporation, was the principal crop grown. Soon canals were constructed to irrigate the mesa land above, and this, in conjunction with heavy irrigation on the terrace lands, raised the water table so close to the surface that much of the land south of Tempe was swamped. Surrounding the swamped area was a large district that was subirrigated but not swamped. A part of these subirrigated nonswamped lands became badly impregnated with alkali and a part remained extremely fertile. Often the dividing fence line between two farms was the dividing line between nonproductive alkali lands and those that were free from alkali and highly productive. Close investigation discloses the fact that the productive fields invariably are those in which surface leveling is carefully done and in which the farmer has continued to apply in the form of flood irrigation all the water coming to him in the mutual ditch.

With subsoil water at a depth of 5 or 6 feet it would still be easily within the capillary power of the soil to raise the water to the surface, and if fluctuations occur damage might follow from the water alone. The good farms alongside of the bad, however, amply testify to the ability of the farmer to prevent the accumulation of salts with the water table within reach of the surface.

Since about the middle of the nineties the subsoil water has been slowly lowering over this area. This is due to several causes. A series of seasons of slight rainfall has cut off much irrigation upon the highlands and reduced the water supply for the lowlands. A drainage ditch was cut to the gravel bed near Double Buttes to develop water for irrigation to the west of these buttes. Several large pumping plants have been installed on the "South Side" to furnish water for irrigation. As the water table has been lowered many fields that were allowed to become heavily charged with alkali during the heavy irrigation periods have been reclaimed. If a series of years of abundant water supply should occur, as now seems assured by the construction of the Tonto Basin reservoir, the water table would in all likelihood be again raised in spite of the present pumping plants and single drainage ditch. If abundant irrigation be again assured the water table should be carefully observed, and if it approach so near the surface that damage may be done, additional regional drainage should be installed to carry off the surplus ground water and maintain the level at a uniform height. Under natural conditions the underground water flows with the grade of the country till it strikes the obstruction formed by the more or less continuous line of hills that extends across the valley from northeast to southwest. The Double Buttes territory forms a part of the range that terminates to the southward in Salt River Mountains. Drainage ditches to tap the gravel and relieve it of its surplus of water should be constructed to pass north or south of the range, either to the drainage of Salt or Gila rivers.

Across the river to the eastward of the Phoenix survey the Pima Indians have reclaimed several hundred acres of land that was originally full of alkali, simply by following the method of heavy surface flooding. Their practice is to check the land in small basins. Each basin is filled with water, which is left to seep into the soil. Irrigation even for melon and vegetable crops is done in the same way, so that the alkali is washed out and further surface accumulations prevented practically without cultivation. This method is wasteful of water, but reclaims the land.

The alkali of the area about Phoenix is mainly on the lowlands along the river, a part of which was irrigated by the race that peopled this country in prehistoric times. The accumulations on these formerly irrigated lands have taken place much in the same way as the accumulations south of Tempe. The solution of the problem is practically the same as in the Tempe area, except that there is very little land that actually needs drainage. Southwest of Phoenix, however, in the St. Johns country, is quite a large alkali area that is due almost wholly to seepage and subirrigation from modern irrigation. If by heavy flooding and the prevention of evaporation the water table is so raised as to swamp the area, it may be necessary to put in a few deep drains. Careful farm practice should reclaim these lands if there should be an abundance of water for irrigation, since they are near the river, which is below the general level and affords a ready escape for the seepage waters.

Examinations of the waters of Salt River show the presence of soluble salts at all times, and at the low stages of the river the percentage is quite high. Sodium chloride (common salt) is the principal salt found in the waters of the river. There is also an excess of calcium sulphate. The salts found in the soil are quite different from the salts found in the water of the river. A marked characteristic of the salts of the soil is the presence of the high percentage of calcium chloride.

Prior to the application of water there were many limestone nodules throughout the subsoil, in some instances forming a continuous sheet or hardpan. When the irrigation water was added to the soil, reactions took place between the sodium chloride and calcium carbonate to form calcium chloride and sodium carbonate, the sodium carbonate being largely neutralized by the gypsum of the water. As very little salts have been leached from the soils into the drainage of the country, all the salts found in the river water and resulting from its action upon the calcium carbonate of the soil are yet found in these soils.

In the lower parts of the valley these same reactions have taken place, but much of the calcium chloride being very soluble, it has been leached into the country drainage and carried away. The alkali of the St. Johns country, having come principally from seepage from modern irrigation, is abnormally high in this salt.

The alkali of the Buckeye area is found in a long, narrow strip of soil occupying a depression that was probably at one time the channel of the Agua Fria River. Its accumulation is due to a water table that comes within capillary reach of the surface. Occupying as it does a long, narrow strip along the bank of the Gila River, the country has good drainage. Heavy floodings and treatment similar to that employed in the reclamation of land near Tempe should reclaim the greater part of this strip. If the natural drainage will not carry off the water thus added to the subsoil, deep drains extending through the alkali belt may be necessary, but no detailed drainage should be necessary, as the soils are leachy and the general drainage good.

FRESNO AREA, CALIFORNIA.

The Fresno area was surveyed in 1900 by Thomas H. Means and J. Garnett Holmes. The area comprises a broad, gently sloping plain, the soils of which are mainly sandy, very leachy and pervious, and of such a character that regional drainage is naturally poorly developed. All irrigation has been comparatively recent. Until about thirty years ago the whole country was thought valuable only for its native vegetation, which was utilized for pasturage. When irrigation began the water table for the whole area mapped was low, in many cases approximately 100 feet below the surface. Early irrigation was very copious, some lands receiving as much as 27 acre-feet per year. These enormous quantities of water soon raised the water table, till at the time of the examination in 1900 some of the lower part of the area was swamped, and much contained excessive amounts of alkali. Practically all of the irrigation takes place in the spring and early summer months, at which time large quantities of water are brought to the region by the several large canals. This heavy seasonal irrigation results in a rapid rise of the water table, which for all the time is high. After the cessation of irrigation the water subsides gradually, to be again quickly raised the following season. Practically all the crops grown are fruits, grapes, and alfalfa, and all of these are injured by the fluctuations of the water table as well as by the accumulation of alkali.

The alkali and possible drainage problems are complicated by the presence of sodium carbonate as a part of the salts and by the calcium and magnesium carbonate hardpan, which underlies the greater part of the area and is a constant source of this salt.

The damaged part of this area presents the conditions of sandy, leachy soils, through which water moves rapidly, but for which surface drainage is lacking; a high and fluctuating water table with consequent accumulations of alkali at the surface; and the complication of both alkali and drainage problems by the presence of hardpan. Prior to the rise of the water table the hardpan gave very little trouble. While its presence may tax the ingenuity of the farmers to create favorable moisture conditions and prevent evaporation from the surface, it is not in most cases sufficiently near the surface or at the present time so indurated as materially to interfere with proper root development or the percolation of water. While the hardpan may complicate matters, it is a problem to be worked out by the individual and does not materially change the main problems. The real problems of the area are to control or lower the water table beyond the root zone, to reclaim lands already alkaline, and to prevent the rise and further spread of the alkali.

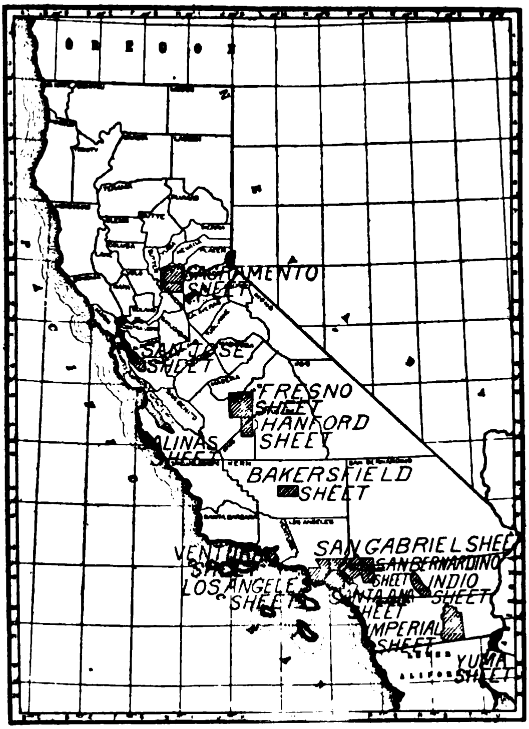

FIG. 4.—Sketch map showing location of areas in which alkali has been studied in California.

The control or lowering of the water table is a definite engineering problem and should be capable of complete solution. The district is one of sandy soils and poor regional drainage; hence to lower the water table drainage should be considered regionally. Drainage may be accomplished either by the construction of gravity drains or by installing pumping plants to supply water for irrigation, and so cutting off the canal supply. Either plan, if comprehensively and intelligently carried out, would accomplish the desired end.

The following table gives a number of analyses of salts of the Fresno district:

Chemical analyses of alkali soils containing no sodium carbonate.

Constituent.	4872. Sec. 19, T. 14 S., R. 22 E., crust.	4841. Sec. 25, T. 14 S., R. 18 E., 0 to 12 inches.	4871. Sec. 7, T. 14 S., R. 23 E., 0 to 24 inches.	4681. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4835. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4676. Sec. 20, T. 14 S., R. 20 E.	4682.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	18.71	12.59	17.25	1.60	9.51	15.96	2.76
Magnesium (Mg)	8.21	5.26	5.50	.74	3.30	9.33	.56
Sodium (Na)	5.34	15.56	7.93	31.11	21.28	....	33.33
Potassium (K)	.92	1.15	3.50	2.63	1.86	9.33	1.55
Sulphuric acid (SO_4)	1.00	1.60	2.33	25.84	4.54	8.66	7.56
Chlorine (Cl)	64.60	60.40	55.71	33.39	54.55	56.66	53.00
Carbonic acid (CO_3)	....	....	....	....	....	Tr.	....
Bicarbonic acid (HCO_3)	1.31	3.44	7.69	4.69	4.96	....	1.24
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	1.38	2.28	3.27	5.43	6.40	12.00	9.40
Calcium chloride ($CaCl_2$)	50.64	34.61	44.75	....	21.08	34.66	....
Magnesium sulphate ($MgSO_4$)	....	....	....	3.66	....	....	1.14
Magnesium chloride ($MgCl_2$)	32.75	20.49	21.91	....	12.81	35.99	1.34
Potassium sulphate (K_2SO_4)	....	....	....	....	....	....	....
Potassium chloride (KCl)	1.74	2.05	6.53	4.97	3.51	17.34	2.96
Sodium sulphate (Na_2SO_4)	....	....	....	28.25	....	....	....
Sodium chloride (NaCl)	12.32	35.77	13.05	51.23	49.39	....	83.64
Sodium carbonate (Na_2CO_3)	....	....	....	....	....	....	....
Sodium bicarbonate ($NaHCO_3$)	1.77	4.79	10.49	6.46	6.81	....	1.70
Per cent soluble salts.	4.61	.87	.86	3.50	.97	.30	8.23

Chemical analyses of alkali soils containing sodium carbonate.

Constituent.	4689. Sec. 2, T. 15 S., R. 19 E., 0 to 12 inches.	4670. Sec. 9, T. 15 S., R. 20 E.	4831. Sec. 3, T. 15 S., R. 19 E., 0 to 12 inches.	4690. Sec. 7, T. 15 S., R. 19 E., 0 to 1 inch.	4668. Sec. 22, T. 14 S., R. 20 E.	4684. Sec. 26, T. 14 S., R. 20 E., 0 to ½ inch.	4839. Sec. 21, T. 14 S., R. 19 E., 0 to 1 inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	Tr.	1.81	2.31	Tr.	3.65	....	1.15
Magnesium (Mg)	Tr.	1.64	Tr.	Tr.	1.99	Tr.	Tr.
Sodium (Na)	33.78	19.34	32.41	35.27	23.80	35.26	36.16
Potassium (K)	1.86	19.43	1.85	1.01	10.86	.68	.83
Sulphuric acid (SO_4)	11.97	12.09	5.55	24.03	10.20	12.31	18.91
Chlorine (Cl)	29.92	41.28	36.49	27.11	39.64	22.40	24.50
Carbonic acid (CO_3)	3.19	4.40	5.00	4.99	9.87	10.58	14.90
Bicarbonic acid (HCO_3)	19.28	....	16.29	7.59	....	18.67	3.55
Phosphoric acid (PO_4)	Tr.	....	....	Tr.	....	.10	....
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	....	6.13	8.13	....	12.36	....	3.91
Calcium chloride ($CaCl_2$)	....	....	....	....	....	....	....
Magnesium sulphate ($MgSO_4$)	....	8.12	....	....	1.82	....	....
Magnesium chloride ($MgCl_2$)	....	....	....	....	6.46	....	....
Potassium sulphate (K_2SO_4)	....	2.33	....	....	....	....	....
Potassium chloride (KCl)	3.46	35.05	3.51	1.93	20.65	1.30	1.56
Sodium sulphate (Na_2SO_4)	17.69	....	....	35.57	....	18.23	23.91
Sodium chloride (NaCl)	46.68	40.59	57.31	43.23	41.30	35.93	39.42
Sodium carbonate (Na_2CO_3)	5.72	7.77	8.68	8.82	17.42	18.72	26.34
Sodium bicarbonate ($NaHCO_3$)	26.45	....	22.37	10.45	....	25.72	4.86
Phosphoric acid (PO_4)	....	....	....	....	....	.10	....
Per cent soluble salts.	1.50	2.32	1.08	8.30	2.41	24.00	9.19

Chemical analyses of alkali soils containing sodium carbonate—Continued.

Constituent.	4688. Sec. 36, T. 14 S., R. 19 E., 0 to ½ inch.	4829. Sec. 31, T. 14 S., R. 20 E., 0 to 12 inches.	4680. Sec. 30, T. 14 S., R. 20 E., 0 to ½ inch.	4677. Sec. 28, T. 14 S., R. 20 E., crust.	4877. Sec. 8, T. 17 S., R. 21 E., 0 to 12 inches.	4886. Sec. 17, T. 17 S., R. 21 E., crust.	4686. Sec. 19, T. 14 S., R. 20 E. 0 to ½ inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	Tr.	3.52	Tr.	2.55	0.48	0.20	Tr.
Magnesium (Mg)		Tr.	Tr.	.50	.16		Tr.
Sodium (Na)	36.46	28.74	36.23	31.03	33.77	34.90	36.03
Potassium (K)	.98	.59	.73	5.96	1.81	1.15	.41
Sulphuric acid (SO_4)	8.22	3.81	8.93	17.84	5.44	17.09	5.17
Chlorine (Cl)	24.97	4.99	15.58	21.86	8.06	2.50	5.81
Carbonic acid (CO_3)	15.26	16.71	20.26	20.31	22.63	23.56	26.30
Bicarbonic acid (HCO_3)	13.61	41.64	17.81		27.65	20.60	26.01
Phosphoric acid (PO_4)	.50		.46				.27
Conventional combinations:							
Calcium sulphate ($CaSO_4$)		5.28		8.32	1.60	.67	
Calcium chloride ($CaCl_2$)		[a] 8.21					
Magnesium sulphate ($MgSO_4$)				2.46	.75		
Magnesium chloride ($MgCl_2$)							
Potassium sulphate (K_2SO_4)				13.28			
Potassium chloride (KCl)	1.86	1.17	1.37		3.47	2.19	.79
Sodium sulphate (Na_2SO_4)	12.16		13.20	3.96	5.50	24.69	7.65
Sodium chloride (NaCl)	39.73	7.04	24.64	36.04	10.72	2.39	8.95
Sodium carbonate (Na_2CO_3)	27.02	29.62	35.81	35.90	39.96	41.67	46.51
Sodium bicarbonate ($NaHCO_3$)	18.73	48.68	24.52		38.00	28.39	35.83
Phosphoric acid (Po_4)	.50		.46				.27
Per cent soluble salts.	6.76	.68	9.92	3.99	3.75	28.22	26.07

Constituent.	4862. Sec. 34, T. 13 S., R. 23 E., crust.	4679. Sec. 22, T. 14 S., R. 20 E., 0 to ½ inch.	4669. Sec. 34, T. 14 S., R. 20 E., crust.	4888. Sec. 9, T. 17 S., R. 22 E., 0 to 24 inches.	4678. Sec. 18, T. 14 S., R. 20 E., crust.	4889. Sec. 11, T. 17 S., R. 21 E., crust.	Standard solution.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	4.58	Tr.	1.75	3.01	0.48	0.04	0.10
Magnesium (Mg)	Tr.	Tr.	.42		.21		
Sodium (Na)	31.46	37.26	30.66	34.19	35.03	41.85	34.24
Potassium (K)	.76	1.12	9.87	.63	7.85	1.26	5.33
Sulphuric acid (SO_4)	5.34	2.31	9.80	7.24	7.13	2.35	18.92
Chlorine (Cl)	3.05	11.99	15.75	2.41	5.82	1.15	29.75
Carbonic acid (CO_3)	30.84	28.71	31.71	33.85	43.48	52.79	11.59
Bicarbonic acid (HCO_3)	23.97	18.44		18.66		.56	
Phosphoric acid (PO_4)		.17					
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	7.48		5.88	10.28	1.62	.10	.32
Calcium chloride ($CaCl_2$)	[b] 6.11						
Magnesium sulphate ($MgSO_4$)			2.03		1.00		
Magnesium chloride ($MgCl_2$)							
Potassium sulphate (K_2SO_4)			7.35		9.43		
Potassium chloride (KCl)	1.37	2.13	12.67	1.15	6.89	2.41	9.77
Sodium sulphate (Na_2SO_4)		3.42				3.36	27.74
Sodium chloride (NaCl)	3.97	18.12	16.03	3.04	4.20		41.63
Sodium carbonate (Na_2CO_3)	48.09	50.76	56.06	59.85	76.88	93.35	20.53
Sodium bicarbonate ($NaHCO_3$)	39.98	25.40		25.68		.77	
Phosphoric acid (PO_4)		.17					
Per cent soluble salts.	1.31	16.42	2.86	1.91	5.81	54.24	

[a] $Ca(HCO_3)_2$.

[b] $CaCO_3$.

The alkali soils normally contain sodium carbonate, but in special cases, which cover but a small part of the total area of alkali lands, sodium carbonate is wanting. The analyses given in the first table show the composition of the soluble portions of a number of such soils. All of the samples, except 4681, instead of showing sodium carbonate show large quantities of chlorine, which must be largely combined with lime and magnesium as chlorides. The accumulation of calcium and magnesium chlorides is the result of the action of sodium chloride upon calcium carbonate. Both being in solution at the same time, calcium chloride must exist in the solution. Calcium chloride is a salt which moves very rapidly in a soil. Some experiments[a] made with various chlorides showed that calcium chloride would be washed from a soil in one-half the time required to leach out the same quantity of sodium chloride. As the water moves through the soil the tendency is for the calcium chloride to move more rapidly than the other salts, and hence it accumulates in the place when these waters have evaporated. The extent of these white alkali spots is not large.

Sample 4681 was collected from a spot which had been treated with gypsum, which accounts for the large quantity of sulphates found in the salts.

The second table contains analyses of samples of alkali crusts which contain sodium carbonate. The analyses are arranged according to the content of sodium carbonate, which varies from nearly 6 per cent to over 93 per cent of the soluble portion of the soil. The principal constituents of the soil are seen to be chlorides and carbonates with bicarbonates. Lime and magnesium are low, so that the salts are largely salts of sodium and potassium. Potassium forms an average of 5 per cent of the soluble matter within the soil. Sulphuric acid is always present, but the quantity is rather variable and on the average constitutes 6 per cent of the total alkali salts. The relation between the carbonates and bicarbonates varies greatly as found in the field. The drying out of the samples in transit to the laboratory so changes the relative proportion of these two salts that a laboratory examination gives no idea of the relations which exist in the undisturbed soil. Field examinations were made of many samples for the relation between carbonates and bicarbonates, and even here the relative proportion is found to vary greatly. Carbonates of sodium and potassium have been generally considered the most harmful salts found in the alkali of the soils. Researches in the laboratory of this Bureau show that the bicarbonates are themselves not as harmful as the carbonates, so that a simple statement of the carbonates and bicarbonates from the laboratory determinations does not suffice for a discussion of the field conditions.

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[a] Yearbook, U. S. Dept. Agr., 1898, p. 498.

These alkali crusts containing sodium carbonate occupy almost the entire area of the alkali lands. White-alkali lands are found in very small spots only. The areas of the various grades of alkali soils, as determined from the map, are as follows:

Areas of the different alkali soils.

Grades of alkali soils.	Acres.	Per cent.
Less than 0.20 per cent alkali	336,300	83.8
From 0.20 to 0.40 per cent alkali	26,300	6.6
From 0.40 to 0.60 per cent alkali	10,150	2.5
Over 0.60 per cent alkali	28,500	7.0
Total area	401,250	....

YAKIMA AREA, WASHINGTON.

In 1901 Jensen and Olshausen made a soil survey of the Moxee and Atanum valleys and the Sunnyside district in Yakima County, Wash. Irrigation was carried on in this region in a limited way as early as 1860, but the advent of the Northern Pacific Railroad in 1883 really marks the beginning of the agricultural importance of the country. The soils are derived mainly from the sediments of former John Day Lake. These lake beds are composed of alternating strata of volcanic dust, gravel, sand, and finer soils and are also interstratified with widely spread sheets of basalt, as well as a number of more local sheets. Since these beds were deposited the underlying lava beds have been raised and broken in places, giving rise to the present series of ridges and intervening valleys. The soil forming the surface of these valleys varies in thickness from a few feet to upward of 50 or 60 feet.

The prevailing type of soil is the Yakima sandy loam, a light-textured, fine gray sandy loam. Volcanic ash is often found in the soil. With few exceptions this soil is well drained and free from excessive quantities of alkali. Some alkali occurs in the subsoil, but unless the surface of standing water approaches sufficiently near the surface of the ground to permit it to reach the top by capillary movement the amount of alkali is not sufficient to prevent the growing of crops. This, however, does take place, and the soil is then rendered unproductive by such accumulations. Another soil type is the Sunnyside sand, a medium to fine sand, much of which is a wind deposit. This soil is usually well drained and free from alkali. Another soil type is "Meadow," found near the streams in the low bottoms. Some sodium carbonate hardpan was found in a few places along Wide Hollow Creek. A lime hardpan lying about 3 feet below the surface is found in the Sunnyside district.

In the Moxee Valley practically the only places containing injurious amounts of alkali in the first 6 feet of soil are in the eastern and southwestern parts of the valley. The alkali found in the southwestern part of this valley is different from that of the eastern part, as it contains more chloride and less normal carbonate. The alkali seems to come from the foothills, where coatings of salt occur on the slopes.

Along Wide Hollow and Atanum creeks alkali conditions are quite serious. Many tracts that were formerly the best of the area have been abandoned to salt grass and greasewood. The mean salt content in the first 6 feet is not great, being in no place more than four-tenths of 1 per cent. Very often, however, the salt in the first foot is from one-half to three-fourths black alkali, while accumulations on the surface are very common. The amount of chloride is surprisingly small. In the section where the water table is nearest the surface (from 3 to 6 feet) the most alkali occurs. The seepage water from irrigation in the upper part of the valley and from the level lands to the north follows the subsoil strata down to the low places, and there, by capillarity, is brought to the surface to evaporate.

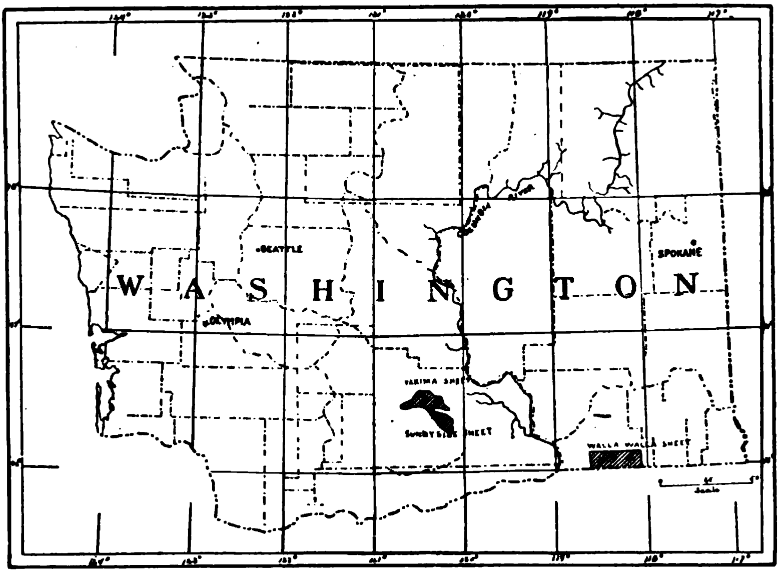

FIG. 5.—Sketch map showing location of areas in which alkali has been studied in Washington.

In the upper part of the Atanum Valley a few trees were found dead or dying on a small spot. Examination of the soil showed in the first foot only 0.15 per cent of salt, while the mean of the first 3 feet was less than 0.10 per cent. As this was mainly carbonate, however, the injurious effects of such slight quantities is accounted for.

In the Sunnyside district the alkali area was not more than 2 square miles in extent. The percentage of salt in this district was from 0.40

to 3 per cent in the first 6 feet, but in about one-half of the affected places it ranged from 1 to 3 per cent. All of this area contained black alkali in the surface foot in quantities varying from 0.05 to 0.30 per cent, but much the greater portion of it carried only 0.05 to 0.10 per cent. The greasewood, which is popularly supposed to indicate alkali soils, was found distributed quite independently either of the total salt content or of the black alkali, though it was always found where a large quantity of salt occurred. The highest percentage of salt occurred in the heaviest phases of the sandy loam. Usually the maximum salt content was in the fourth or fifth foot.

There were alkaline carbonates in all the tests made, and sulphates were always present. The chlorides varied somewhat in relative quantity, but were never high, and the amount of bicarbonate was also moderate. Neither the percentage of the total salt nor of black alkali was high where the soil was light and underlain with sand. In the Parker bottoms a little alkali was found, which was supposed to be black alkali. The soil was colored dark brown and black in places, resembling black alkali, but the salt was bicarbonate and sulphate. It is known that bicarbonates and sulphates have the power of charring organic matter to a slight extent, but the black color may also have been due to the presence earlier in the season of alkaline carbonate which had been converted into the bicarbonate later by aeration. While the soils in the Sunnyside district do not contain any large amount of alkali, great care must be exercised in the use of irrigation water or trouble will ensue.

The following tables contain the results of chemical analyses of alkali in soils:

Chemical analyses of salts in alkali soils.

Constituent.	5815. Meadow near NW. cor. sec. 1, T. 12 N., R. 18 E., soil 0 to 12 inches.	5811. Meadow near NW. cor. sec. 1, T. 12 N., R. 18 E., soil 0 to 12 inches.	5816. Under No. 5815, sandy loam, 12 to 24 inches.	5812. Under No. 5811, sandy loam, 12 to 24 inches.	5813. Under No. 5812, sandy loam, 24 to 36 inches.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	0.88	3.42	6.28	4.49	4.93
Magnesium (Mg)	.88	3.42	2.09	2.62	2.05
Sodium (Na)	30.69	28.52	19.46	16.11	14.00
Potassium (K)	5.07	4.94	4.79	8.61	9.05
Sulphuric acid (SO_4)	12.80	6.46	.59	1.49	4.52
Chlorine (Cl)	4.63	11.03	4.19	2.62	3.70
Carbonic acid (CO_3)	26.50	42.21	17.37	11.99	8.64
Bicarbonic acid (HCO_3)	18.55		45.23	52.07	53.11
Phosphoric acid (PO_4)				Tr.	
Conventional combinations:					
Calcium sulphate ($CaSO_4$)	2.86	9.12	.89	1.87	6.17
Magnesium sulphate ($MgSO_4$)	4.19				
Potassium chloride (KCl)	9.71		8.98	5.61	7.82
Sodium chloride (NaCl)					
Sodium bicarbonate ($NaHCO_3$)	25.40		22.46	36.72	45.28
Sodium carbonate (Na_2CO_3)	46.80	66.94	30.85	13.86	6.58
Sodium sulphate (Na_2SO_4)	11.04				
Calcium chloride ($CaCl_2$)		1.90			
Magnesium chloride ($MgCl_2$)		13.30			
Potassium carbonate (K_2CO_3)		8.74		9.73	8.64
Calcium bicarbonate ($Ca(HCO_3)_2$)			24.25	16.48	13.17
Magnesium bicarbonate ($Mg(HCO_3)_2$)			12.57	15.73	12.34
Per cent soluble	.92	.52	.67	.53	.48

Constituent.	5802. W. cen. sec. 24, T. 8 N., R. 22 E., sandy loam, 0 to 12 inches.	5803. Under No. 5802, sandy loam, 24 to 36 inches.	5804. Under No. 5802, loam, 48 to 60 inches.	5787. SE. cor. sec. 23, T 9 N., R. 22 E., loam, 0 to 12 inches.	5788. Under No. 5787, loam 24 to 36 inches.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	2.12	1.38	0.91	Tr.	1.86
Magnesium (Mg)	2.66	1.58	.91	0.38	1.70
Sodium (Na)	20.74	26.55	29.10	25.25	26.82
Potassium (K)	7.45	5.94	3.67	10.48	4.80
Sulphuric acid (SO_4)	13.83	23.37	22.68	32.04	27.92
Chlorine (Cl)	7.98	1.98	3.21	18.06	21.72
Carbonic acid (CO_3)	7.98	13.86	12.41	.98	5.42
Bicarbonic acid (HCO_3)	37.24	22.77	24.05	12.81	9.76
Phosphoric acid (PO_4)		2.57	3.06	Tr.	
Conventional combinations:					
Calcium sulphate ($CaSO_4$)	6.91	4.75	3.06	Tr.	6.35
Magnesium sulphate ($MgSO_4$)	12.23	7.72	3.67	1.74	8.37
Potassium chloride (KCl)	14.36	4.15	6.89	20.00	9.14
Sodium chloride (NaCl)	1.59			13.98	28.50
Sodium bicarbonate ($NaHCO_3$)	51.08	31.50	33.08	17.67	13.33
Sodium carbonate (Na_2CO_3)	13.83	24.57	21.90	1.74	9.61
Sodium sulphate (Na_2SO_4)		14.65	26.19	44.87	24.70
Potassium sulphate (K_2SO_4)		8.31			
Sodium phosphate (Na_3PO_4)		4.35	5.21		
Per cent soluble	.38	1.01	1.30	1.03	1.29

Examination of the underground and seepage waters of the Atanum Valley showed them to contain bicarbonate as the principal salt, with only traces of chloride. In the Sunnyside district it was found that the well water was characterized by a rather light percentage of salt, the greater part of which was composed of sulphate and bicarbonate, with smaller quantities of chloride.

In considering the drainage and reclamation of alkali lands Jensen states that the best way to reclaim lands that were originally good and to prevent good land from becoming filled with alkali is to keep the subsoil and seepage waters that carry dissolved salts sufficiently far below the surface to prevent any accumulation of salts through evaporation. If the soil is originally charged with alkali, there is but one sure and permanent cure, and that is to dissolve out the excess of soluble salt by moderate but frequent applications of good water, at the same time draining the water out of the subsoil.

The cause of the damaged lands in Wide Hollow and the Atanum Valley is pointed out. The salts accumulated in these places are alkaline carbonates, or black alkali, and an examination of the seepage water shows that it carries in all cases more than a normal quantity of bicarbonate but no normal carbonate. Examination also showed that the seepage or subsoil water was sufficiently high to be brought to the surface by capillarity of the soil grains, there to be evaporated. There can be but one consequence—the comparatively harmless bicarbonate will lose through evaporation some of its carbon dioxide and be converted into the normal carbonate. As the soil is light in texture in this area, the capillary action goes on quite rapidly. It will be useless, therefore, to try to effect a permanent cure by attempting to change the character of the salt by application of some other salt, as gypsum, for while this will change some of the black alkali to white alkali it only adds more salt to the surface foot, already containing an excess, without in the least decreasing the tendency to form black alkali, which will continue to accumulate as long as the subsoil waters containing bicarbonate are near enough to the surface to be evaporated.

Jensen also calls attention to the dangerous practice in Wide Hollow of allowing the seepage water from above to subirrigate the land. This is a good method to increase the salt content of the soil, and the nearer the water approaches the surface and the longer the practice continues the more salt there will be accumulated. Wide Hollow waste slough forms an excellent natural drainage channel from 5 to 10 feet below the surface of the soil. The soil is light in texture, readily permitting water to percolate through it, and frequent applications of water and a few drains about 4½ feet deep would accomplish much toward reclaiming the land. Another good natural drainage channel is the northern branch of Atanum Creek. Examples of the good effect of drainage in a small way are cited.

A few attempts at reclaiming alkali land have been made in the lower part of Atanum Valley by building a dike around a piece of land and running sufficient water into the inclosed area to cover the field.

After allowing it to stand for a time, the dike is cut and the water drained off. As would be expected, such attempts have usually resulted in the accumulation of more alkali, rather than in reclaiming any portion of the land.

In the Sunnyside district reclamation is perhaps a more difficult problem. The soil is a heavy one in which alkali is found, the maximum amount occurring within 4 or 5 feet of the surface. The absence of any natural drainage channels makes it necessary to dig long ditches to the river.

BOISE AREA, IDAHO.

A study of the soil and alkali conditions of the Boise area was made in 1901 by Jensen and Olshausen. This area contains about 400 square miles and is situated in the southwestern part of the State. Before the building of the Oregon Short Line Railroad, which was completed in the early eighties, the development of agricultural interests in the Boise Valley was very slow.

The principal type of soil is the Boise sandy loam, a grayish sandy loam with a loam or clay loam subsoil, which in turn is underlain with sandy loam, or sometimes a sand cemented together and forming a hardpan. This is a sedimentary soil and was probably originally derived from the decomposition of basaltic material. The Boise loam, another important soil type, occurs on the mesas and slopes of terraces south of Boise River. The surface soil is a sandy loam underlain by loam which sometimes grades into clay loam and is underlain at about 2 feet with sandy loam or fine sand which often forms a hardpan. The Deer Flat sandy loam to a depth of 2 feet is a red sandy loam with some coarse sand. The subsoil is light in texture and is readily permeable to water. The Caldwell sandy loam is an alluvial soil of recent origin, consisting of sandy material sometimes containing gravel. Much alkali carbonate occurs in this soil.

Hardpan is quite generally found in the central and eastern parts of the area. Except along the slopes of terraces and drains it does not occur on the surface, and there are usually several layers of it, the depth of the first layer varying from a few inches to about 5 feet. As the subsoil water is usually some distance below the surface it is somewhat difficult to account for the presence of hardpan in the Boise Valley. Since hardpan in this area invariably occurs at the change downward, from a heavier to lighter soil, it is fair to assume that an important factor in its origin is the mechanical characteristics of the soil itself. The moisture in descending through the soil dissolves a part of the more soluble salts and a part of the carbon dioxide gas, more plentiful in the soil than in the atmosphere. This forms a solution which is capable of dissolving a much larger quantity of calcium and magnesium carbonates than water free from carbon dioxide can dissolve. When this solution descends through the heavier or finer grained soil, the soil spaces, being small, will be practically filled and a chemical action will take place by which the calcium and magnesium carbonates in the soil will be dissolved, forming the hydrogen carbonates of these bases, but in the lighter soil the air spaces and the surface of the individual soil grains are larger and as the solution passes through it will not be sufficient to fill all air spaces. There will then result a lowering of the partial pressure of the carbon dioxide and a partial liberation of this constituent of the solution, with the result that part of the calcium and magnesium hydrogen carbonates in the solution will be changed to the more insoluble normal carbonates of these bases, and will form as a precipitate around the soil grains. This occurring at the change from a heavier to a lighter soil texture, will give rise to the formation of the hardpan in the lighter rather than in the heavier soil, as is actually the case. This same explanation would hold if the subsoil water were near enough to the surface to reach it by capillarity, bringing with it the dissolved carbon dioxide and soluble salts from below, and there is no doubt that the process is actually reversed after heavy rains or excessive irrigation.

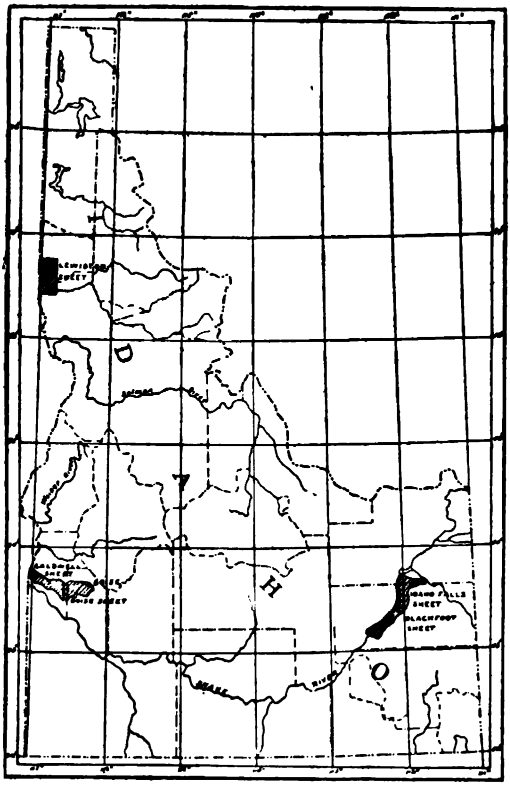

FIG. 6.—Sketch map showing location of areas in which alkali has been studied in Idaho.

The greater part of the Boise area was found to contain less than 0.20 per cent of salt in the first 6 feet, but there were some minor exceptions. Between Meridian and Caldwell there were a number of bare spots in sagebrush land. The absence of vegetation was due to the high salt content of the soil and the physical conditions of the soil itself. Determinations of the salt found in these spots showed that the mean percentage of salt was usually from 0.40 to 0.60 per cent in the first 6 feet. The maximum was usually in the first or second foot, the salt content then decreasing with only a small quantity in the fifth or sixth foot. The distribution of the salt in the soil depends upon the influence of the subsoil water and surface irrigation. On the uncultivated uplands the maximum was found either in the fourth or fifth foot, while in the lower areas in the alluvial soils the maximum was found in the surface foot, with generally but a small percentage farther down. The relation of the various components of the salt to one another also varies with the condition of the subsoil water.

The highest percentages of salts found in the bench soils, except in surface accumulations, were found on or near the slopes of drains and bluffs, where the soil moisture first approaches the surface, carrying with it the salt in solution. In the bench lands the soil moisture and subsoil water carrying the salt in solution naturally gravitate toward the lower creek and river bottoms. This process, going on continually, raises the water table in these lowlands. As the soil has good natural drainage in these places the water in the lowlands constantly carries the salt away, leaving only as much salt in the soil as the water itself is capable of giving to it, which depends upon the concentration of the subsoil water. In the bottoms the subsoil water is near the surface, being found at a depth of from 3 to 7 feet when the examination was made. This is near enough to favor capillary movement of the water toward the surface, and accounts for the surface deposits found there, as well as for the fact that the maximum salt content is in the surface foot. Below this depth there is little salt. On the virgin soils of the bench lands the moisture does not reach the surface and consequently the salt does not, the maximum being found either at the lower limit of the downward movement of the surface moisture or near the upper limit of the capillary movement of the subsoil water.

In but few places on the bottom lands did the total salt content in the first 6 feet exceed 0.40 per cent, most of which was in the surface foot, from one-fourth to five-eighths being alkali carbonates. As a rule, chlorides and sulphates were not present in large quantities in the alluvial soils, the salt consisting principally of carbonates and hydrogen carbonates. On the bench lands the sulphates and carbonates were more abundant, forming a large portion of the total salt content. The reason for a smaller percentage of sulphates and chlorides in the river soils than in the bench lands, the same concentration considered, is undoubtedly due to the fact that these constituents have either been carried away in the process of formation of the river soil, or if they have ever been present in large quantities have been dissolved out and carried away by irrigation water or subsoil water, or both. The alkaline carbonates were present in much larger quantities in the surface foot in the river-bottom soils than in the bench soils, while the sulphates and chlorides have been washed out of the river soils by the movement of the subsoil water and have not been replaced as rapidly with the salts from the subsoil or from the waste water from the bench lands. The alkaline carbonates were found to be constantly increasing in the river soils. The source of these salts is doubtless the seepage water from the bench lands, which contains a little alkali carbonate and much hydrogen carbonate. The latter reaches the surface by capillarity, there to lose some of the carbon and form alkali carbonates.

Chemical analyses of soluble salts in alkali soils.

Constituent.	5824. W. cen. sec. 20, T. 5 N., R. 5 W. Subsoil of Deer Flat sandy loam 24 to 60 inches.	5838. Cen. sec. 15, T. 4 N., R. 4 W. Soil of Caldwell sandy loam 0 to 12 inches.	Standardization solution of Boise Valley.	X. Alkali, surface deposit.	5852. Alkali, surface deposit.	5851. Alkali, surface deposit.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	2.05	0.18	Tr.	0.37	1.75	0.17
Magnesium (Mg)	2.05	.18	0.31	.47	1.24	.09
Sodium (Na)	15.22	31.25	34.46	30.58	29.02	34.70
Potassium (K)	20.51	5.23	1.05	2.28	.97	.92
Sulphuric acid (SO_4)	8.88	12.31	31.71	48.74	54.91	10.04
Chlorine (Cl)	40.87	3.85	6.29	6.63	11.53	3.38
Bicarbonates (HCO_3)	10.42	23.35	9.58	6.93	.53	26.88
Carbonic acid (CO_3)		33.65	16.29	4.00	.05	23.69
Phosphoric acid (PO_4)			.31	Tr.		.13
Nitric acid (NO_3)						Tr.
Conventional combinations:						
Calcium sulphate ($CaSO_4$)	6.83	.64	Tr.	1.28	5.93	.57
Magnesium sulphate ($MgSO_4$)	5.10	.82	1.53	2.20	6.15	.41
Magnesium chloride ($MgCl_2$)	3.93					
Potassium chloride (KCl)	38.98	8.08	1.98	4.34	1.84	1.75
Sodium chloride (NaCl)	30.79		8.84	7.54	17.56	4.19
Sodium bicarbonate ($NaHCO_3$)	14.37	31.27	13.20	9.55	.72	36.97
Sodium sulphate (Na_2SO_4)		16.54	45.13	8.01	67.70	14.12
Sodium carbonate (Na_2CO_3)		41.55	28.78	7.08	.10	41.75
Potassium bicarbonate ($KHCO_3$)		1.10				.42
Sodium phosphate (Na_3PO_4)			.54			
Total salt content	1.17	2.17	[a] 3.529	14.83	20.25	43.22

[a] Grams per 100 cubic centimeters.

The reclamation of the alluvial soils will depend upon the removal of the underground water, since this is the principal cause of the formation of the black alkali in these areas. As there are many natural sloughs leading to the river that could be used as main drains, the reclamation of these areas would not be difficult. In the case of the small black alkali spots it is different, but deep cultivation and generous applications of irrigation water would do much toward their amelioration.

HANFORD AREA, CALIFORNIA.

This area was surveyed in 1901 by Macy H. Lapham and W. H. Heileman. The Hanford area consists of 216 square miles, lying near the geographical center of the San Joaquin Valley. It is agriculturally important, because of its production of raisin and wine grapes and deciduous fruits, and also its production of grains, hay, and dairy products.

The region consists of broad and extensive delta deposits laid down by the waters of Kings River and its tribuatries, spread over the valley floor and sloping toward the southwest, with a fall of some 3 or 4 feet to the mile. The natural slopes are so gradual and uniform as to be hardly sensible, and the area is cut by a network of blind sloughs and former stream channels. Natural drainage is at an advanced stage, the beds of the frequently shifting streams being rapidly filled with sediments. When not protected by artificial levees, the land adjacent to the Kings River bottoms is subject to overflow during periods of flood.

The prevailing soils are sands and sandy loams, deposited as broad, nearly level areas or as slightly elevated irregular bodies, elongated strips marking former stream courses. They are generally of medium to fine texture, frequently very micaceous, of open, porous structure, and are made up largely of granitic material. In the types occurring along the northern and northeastern boundaries of the area there is a liberal admixture of volcanic material rich in the common alkali salts. It is from these volcanic ash soils, locally known as the "white-ash lands," which are strongly impregnated with alkali and occupy extensive areas to the northward from Kings River, that the soils lying to the southwest—which are of a more porous structure and in themselves not originally impregnated with alkali salts—receive their drainage. The evils of this unfortunate condition are apparent, the alkali in these soils spreading and encroaching more and more upon the valuable fruit, vineyard, and grain lands of the central part of the area.

The system of irrigation as practiced in the Hanford area consists, essentially, in the saturation of the subsoils by seepage or subirrigation. Water is rarely, if ever, applied to the surface of the soil. The main canals and larger tributaries generally follow the higher sandy ridges. From these the water is led in small ditches or furrows elevated slightly above the surface of the fields. These waterways are constructed upon a very slight grade maintained by frequent check weirs. During the early spring months the canals and distributing ditches are filled to their full capacity and the water maintained at a high level. This results in a rapid movement of water by lateral percolation through the porous subsoils until these are completely saturated and the water table is raised nearly to the surface. This process is allowed to continue until the surface soil of the fields is thoroughly moistened. In this manner the water table of the heavily irrigated part of the area has been raised in general 10 or more feet. As the moisture is removed from the soil surface by evaporation it is constantly supplied from below by the saturated, porous subsoils, through which capillary movement is unusually rapid. By lateral and upward movement the readily soluble alkali salts are thus removed from heavily impregnated subsoils, transported by percolating waters, and brought to the soil surface, where they are deposited at the immediate surface or within the root zone of crops. Even when occurring in but minute and limited quantities throughout the subsoils they may thus become concentrated at the surface and work extreme injury. The irrigating waters of the area are of excellent quality and free from any injurious amounts of alkali salts, and it is from the soils themselves, and mainly from the concentration of salts by evaporating soil waters that the damage originates. That the injury has not spread more rapidly is largely due to the checking of the otherwise rapid rate of evaporation from the soils by frequent cultivation and by the maintenance of an excellent state of tilth upon most of the vineyard and orchard lands. Owing to the abundant water supply and a cheap, simple, and effective means of application there is a tendency in the Hanford area toward the use of excessive quantities of water for irrigation purposes.

At the time the alkali survey of this area was made, during the early summer of 1901, nearly one-half of the lands were more or less affected by an excess of alkali salts, which were rapidly spreading in extent and increasing in concentration.

In the northern and northeastern parts of the area, chiefly upon the so-called "white-ash lands," previously mentioned, the conditions were very bad, several square miles having been abandoned for agricultural purposes, save as they furnished a scanty pasturage. Natural drainage is here defective, and the alkali salts occur in concentrated form both in the surface and in the alkali-lime-carbonate hardpan of general occurrence in the subsoil. Extending in a southwesterly direction across the area and in the path of the natural drainage slopes were a large number of small patches, chiefly upon the porous, fine micaceous land, that were unfit for crops. With the exception of a few irregular bodies the bottom lands in the vicinity of Kings River were free from alkali salts in injurious amounts. The central and western parts of the area were generally free from alkali in extreme concentrations, but contained many small and irregular patches over which the salts occurred in such quantities as to more or less reduce production. Since these parts of the area are largely devoted to fruit culture, the spread of the salts has been less rapid than upon those sections devoted to some crop in which cultivation plays a less important part.

The common alkali salts of the area consist principally of sodium and magnesium sulphates with about 24 per cent of the extremely injurious sodium carbonate, or black alkali, and about 10 per cent sodium chloride. The black alkali is of general occurrence whenever the total salts reach the more concentrated limits and at once makes itself known by the compact, puddled condition of the soil and in the inky black appearance of the drainage and seepage waters collected in pools.

In the following table is given the average composition of the alkali in the soils of the Hanford area:

Chemical analysis of composite sample of alkali soils from Hanford area.

Ions.	Per cent.	Conventional combinations.	Per cent.
Calcium (Ca)	0.45	Calcium sulphate ($CaSO_4$)	1.53
Magnesium (Mg)	.36	Magnesium sulphato ($MgSO_4$)	1.78
Sodium (Na)	33.68	Sodium sulphate (Na_2SO_4)	52.52
Potassium (K)	.79	Potassium chloride (KCl)	1.51
Sulphuric acid (SO_4)	37.98	Sodium chloride (NaCl)	9.35
Hydrochloric acid (HCl)	6.38	Sodium carbonate (Na_2CO_3)	23.87
Carbonic acid (CO_3)	13.50	Sodium bicarbonate ($NaHCO_3$)	9.44
Hydrogen carbonic acid (HCO_3)	6.86		
Total	100.00	Total	100.00

On land containing less than 0.20 per cent of alkali all crops suited to the soil type do well. Where the land contains from 0.20 to 0.40 per cent of salts, most crops can be grown, although when the major limit (0.40 per cent) is reached certain crops, notably alfalfa, most tree fruits, grapes, and grain crops, begin to suffer. However, pears and figs, if the land be well drained, and beets, onions, sorghum, and some grasses, including alfilaria and sporobolus, will grow quite well on such land. On land containing from 0.40 to 0.60 per cent of alkali few crops will survive; only the salt grasses, alkali heath, and various weeds will be able to subsist. No cultivated plants, except a few pear trees, were found on land containing 0.60 per cent of alkali. Land containing from 0.60 to 1 per cent is practically worthless. Pear trees may grow, if well started and if all the alkali is in the first 2 feet, but in general, aside from some pasturage, land of this class has little agricultural value. Land containing from 1 to 3 per cent of alkali is so salty that many of the alkali grasses will not grow upon it.

The acreage of land carrying the various percentages of alkali is as follows:

Areas of alkali land, classified according to degree of salt content.

Grade of alkali soil.	Acres.	Per cent.
Less than 0.20 per cent alkali	82,100	58.4
From 0.20 to 0.40 per cent alkali	40,340	29.2
From 0.40 to 0.60 per cent alkali	7,720	5.6
From 0.60 to 1 per cent alkali	1,770	1.3
From 1 to 3 per cent alkali	6,310	4.5
Total	138,240	....

Under the conditions of irrigation and management existing at the time of the survey, the more or less complete ruin of at least a large portion of the area seemed probable, and the gradual abandonment of tracts to alkali-resistant crops, then to pasture, and finally to complete loss, seemed a certainty.

Not only are excessive amounts of water applied to the land in irrigation, but the process of saturating the subsoils and keeping the lands continually wet is hastened by artificially damming the slough channels—the natural drainage outlets—in order further to raise the water table. The efforts of nature herself in providing natural drainage outlets have thus been perverted and turned into positive injury. Yet few sections possess greater natural facilities for freeing the soils from noxious alkali salts and maintaining them in a productive condition.

With the adoption of remedial measures in opening the natural drainage channels by making a few artificial cuts, by greater economy in the use of irrigation waters, and by the practice of the more expensive, but less injurious, methods of irrigation by surface flooding nature would herself repair much of the injury.

Upon some of the heavily impregnated alkali soils of the area the opening of drainage canals and the laying of tile-drains at frequent intervals would be necessary.

LOWER SALINAS VALLEY, CALIFORNIA.

In 1901, Macy H. Lapham and W. H. Heileman made a survey of the lower Salinas Valley. This area covers the Salinas Valley from King City northward. Its chief agricultural importance arises from its production of grains, sugar beets, potatoes, beans, and apples. The summer climate of this area is marked by high temperatures, low relative humidity, and strong daily winds increasing in velocity with their progression up the valley, these conditions promoting excessive evaporation from the soil surface. The soils and subsoils of the area are, however, capable of retaining large quantities of water in spite of these influences.

The soils naturally fall into three classes—upland soils, valley soils, and recent sedimentary soils—each of which is quite distinct in its typical form and often separated from the others by marked topographic features. The soils are mainly of alluvial or colluvial origin and are derived by weathering and waste of a complex variety of rocks of the surrounding mountains. In texture they range from incoherent sands to heavy and sticky adobes.

The water supply derived from the streams of the area is inconstant and is limited during dry seasons, while that derived from pumping from an underground source is costly. Irrigation is practiced in general upon the heavy adobe lands of the valley, devoted to sugar-beet culture and to the raising of limited quantities of alfalfa and special crops. The higher slopes devoted to the growing of grains are unirrigated. The character of the irrigation waters is generally good.

Many of the waters from the surface wells in the upper part of the valley carry in solution large quantities of the common alkali salts, indicating that these are present in the deeper subsoils. Owing to the limited extent of irrigation, good natural drainage, and depth to water table, these alkali salts have not as yet become concentrated within the root zone of the crops. In the lower part of the valley the alkali salts frequently make their appearance in slight crusts in local valley depressions, and in the vicinity of the open sloughs, of frequent occurrence in the lower valley. They are, however, rarely concentrated enough to affect the most sensitive field crops. Examination reveals the presence of small quantities of alkali salts to great depth in the subsoils. In the vicinity of Monterey Bay and its tidal marsh lands, which extend as small bodies for some distance into the area, the soils are saturated with strong solutions of marine salts. Some of these tidal lands have been partially reclaimed for grazing purposes by a system of tidal flood gates and shallow trenching and cultivation.

While the present alkali condition of the Salinas Valley is a matter of but slight importance, observations indicate that in the aggregate a large quantity of the common alkali salts occur in the valley subsoils, and that in the event of future extension of irrigation and the use of large quantities of water, concentration may occur in certain areas of restricted drainage to such an extent as greatly to damage crops. The first appearance of salts in injurious quantities should be the signal for immediate drainage of the affected districts.

VENTURA COUNTY, CAL.

In the summer of 1901 a soil survey was made by J. Garnett Holmes and Louis Mesmer of the agricultural lands of Ventura County, Cal. This part of the county is included in the valleys and combined deltas of Ventura and Santa Clara rivers. These lands are bounded on the southwest by the Pacific Ocean and on the land sides by rough hills or mountains.

There is an average rainfall of about 15 inches, all occurring during the winter and early spring. The climate is semitropical. There are frequent variations from the normal of 15 inches rainfall, but with careful cultivation there is rarely an entire failure of crops on unirrigated lands. In fact, comparatively little irrigation is practiced, most of the farmers depending wholly upon rainfall for moisture for their crops.

The soils of the delta are principally sand, sandy loam, and loam, all of which are leachy and take water readily. Potentially the valleys and delta are well supplied with water for irrigation. The soils are such that if they receive an amount of water during the winter months equal to 15 inches of rainfall, a good yield of the principal crops grown—Lima beans and sugar beets—may be obtained without further irrigation. Irrigation while the crops are growing increases the yield, but paying crops may be obtained from winter irrigation alone. Artesian water may be obtained at reasonable depths for all the lower part of the delta, which would furnish a constant supply for summer irrigation. Santa Clara and Ventura rivers drain a vast area that is for the most part practically untimbered. During the flood or winter season these streams are raging torrents, but shortly after the rains cease they become almost dry. All this summer flow is used for irrigation, but irrigates only a very small part of the lands. Summer irrigation is applied by the furrow method. A few practice summer irrigation from artesian wells.

All the lower part of the delta extending along the coast has a water table that is only from 4 to 10 feet below the surface at the driest time of the year. During the rainy season water stands in many small lakes along the ocean side, which are separated from the sea only by low dunes of beach sand.

The survey made in 1901 showed about 9,000 acres of these low, moist lands so filled with alkali as to produce almost no cultivated crops. Since shallow-rooted annuals are principally grown, fluctuations of the water table are of little moment, the real problem of the area being to reclaim these alkali lands, so that crops may be grown. The soils are nearly all quite sandy and leachy, and nature has supplied main drainage ways for much of the affected lands. Broadly speaking, flood irrigation, with careful cultivation, will reclaim the lands. A few drains will have to be installed, but the principal innovation must be irrigation. Enough water annually flows to the sea during the high-water season to flood heavily the entire delta. The preparation of the lands for winter flooding, and the construction of canals to divert these flood waters to the lands, with adequate drainage provided for, would permit heavy flooding during the winter months. This would supply sufficient moisture for fair summer crops and at the same time reclaim the lands from alkali. The development of artesian water would allow furrow irrigation during the summer months and the production of maximum crops. The water of both the river and artesian wells is of good quality for irrigation and entails no risk in its use.

Appended is a table of analyses of the salts of the area:

Chemical analyses of alkali soils and crusts.

Constituent.	East side of Saticoy.	4795. Lot 48 E. of ranch house.	One-eighth mile W. of Woods and Leguma roads.	4792. 100 yards S. of experiment station house.	4662. 2 miles SW. of ranch house.	Near mouth of Santa Clara River, S. side.	4798. 50 yards E. of pond No. 2.	One-quarter mile W. of Hueneme slough.	Standardization solution.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	0.59	1.46	1.66	1.31	2.42	4.34	1.29	1.78	0.39
Magnesium (Mg)	5.88	6.47	3.51	5.32	5.68	2.41	7.61	1.34	4.76
Sodium (Na)	22.22	20.55	19.88	22.96	18.26	25.46	20.84	32.92	25.28
Potassium (K)	.82	1.42	1.42	.99	5.48	.99	1.10	1.54	.58
Sulphuric acid (SO_4)	62.05	59.39	61.60	57.38	54.62	50.35	43.02	12.98	56.08
Chlorine (Cl)	7.38	10.16	10.53	11.19	13.30	14.98	25.43	49.19	11.91
Carbonic acid (CO_3)	.03	....	.18	....	.27	....	.71	....	....
Bicarbonic acid (HCO_3)	1.03	.64	1.25	.85	....	1.47	....	.25	1.00
Conventional combinations:									
Calcium sulphate ($CaSO_4$)	2.81	4.94	5.66	4.42	8.21	14.77	4.40	6.04	1.37
Magnesium sulphate ($MgSO_4$)	29.24	32.08	17.40	26.32	28.13	11.94	37.72	6.67	23.64
Sodium sulphate (Na_2SO_4)	53.53	44.78	56.99	49.21	29.09	46.14	14.52	5.11	53.75
Potassium sulphate (K_2SO_4)	....	....	....	....	12.20	....	....	....	....
Sodium chloride (NaCl)	10.81	14.65	15.25	17.00	21.91	23.24	40.34	78.90	18.77
Potassium chloride (KCl)	1.51	2.70	2.72	1.88	....	1.89	2.08	2.94	1.10
Sodium carbonate (Na_2CO_3)	.69	....	.26	....	.47	....	.94	....	....
Sodium bicarbonate ($NaHCO_3$)	1.41	.85	1.72	1.17	....	2.02	....	.34	1.37
Per cent soluble	43.45	28.13	38.52	28.23	19.93	16.43	25.48	41.71	6.70

Chemical analyses of alkali soils and crusts.

Constituent.	4793. 250 yards S. of experiment station slough.	4796. Post 44.	One-fourth mile W. of Patterson ranch house.	Lot 56, O. la Colonia ranch.	4794. Dunes W. of Post 49.	4791. Pond W. of Post 25.	4665. One-half mile E. of ranch house.	4 miles E., 1 mile N. Hueneme.	2 miles E. of Hueneme.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	1.39	1.20	1.01	0.91	0.89	0.86	1.54	1.34	3.07
Magnesium (Mg)	6.38	5.59	5.92	3.87	6.66	7.78	7.63	2.37	2.11
Sodium (Na)	20.33	21.59	25.84	25.11	20.42	19.13	13.13	27.38	25.46
Potassium (K)	.77	1.17	.58	.82	1.11	.50	8.26	.57	1.14
Sulphuric acid (SO_4)	67.41	65.30	62.51	64.16	65.49	66.74	63.92	61.89	60.49
Chlorine (Cl)	2.72	3.72	3.78	4.32	4.63	4.65	5.28	6.02	6.34
Carbonate (CO_3)	....	....	....	.08	....	....	.21	....	.12
Bicarbonate (HCO_3)	1.00	1.43	.36	.73	.80	.35	....	.43	1.27
Conventional combinations:									
Calcium sulphate ($CaSO_4$)	4.71	4.07	3.43	3.10	3.00	2.92	5.23	4.57	10.42
Magnesium sulphate ($MgSO_4$)	31.59	27.69	29.36	19.55	33.02	38.55	37.81	11.75	10.43
Sodium sulphate (Na_2SO_4)	57.51	59.64	60.24	68.84	54.79	50.19	29.45	72.92	67.38
Potassium sulphate (K_2SO_4)	....	....	....	....	....	....	18.40	....	....
Sodium chloride (NaCl)	3.33	4.39	5.36	5.79	5.98	6.92	8.71	9.06	7.66
Potassium chloride (KCl)	1.47	2.24	1.11	1.57	2.12	.96	....	1.10	2.17
Sodium carbonate (Na_2CO_3)	....	....	....	.14	....	....	.37	....	.19
Sodium bicarbonate ($NaHCO_3$)	1.39	1.97	.50	1.01	1.09	.46	....	.60	1.75
Per cent soluble	36.05	37.56	49.25	63.85	57.64	70.96	15.06	28.67	23.28

The analyses given in the above tables show a decided similarity in the salts of the crusts and the salts of the river and the artesian belt fed from the river. This justifies a presumption that the alkali has been brought into the valley in the waters of the river. The only possible local source would be the ocean, but there is nothing in the analyses of any of these samples that in any way indicates such an origin. The alkali, when present in harmful quantities, has been concentrated by long-continued evaporation of moisture at the surface of the soil. This moisture is furnished by capillarity whenever the subsoil water rises above a certain depth—a depth measured by the power of attraction latent in the several soil types. Under most of these soils the subsoil water is sufficiently close to the surface to make such connection possible during the greater part of the year. Whenever there is an accumulation of alkali of any kind in sufficient quantity to damage crops there is found associated with it this high water table, and usually the alkali is in a soil of great capillary power.

In the following table is shown the relative extent of the different grades of alkali lands.

Areas of different grades of alkali lands.

Grade of alkali soil.	Acres.	Per cent.
Less than 0.20 per cent	129,619	84.3
From 0.20 to 0.40 per cent	8,742	5.7
From 0.40 to 0.60 per cent	3,808	2.4
From 0.60 to 1 per cent	2,931	1.9
From 1 to 3 per cent	4,122	2.7
Over 3 per cent	4,582	3.0

The agricultural part of southern California proper is made up of the San Fernando, San Gabriel, and San Bernardino valleys and the Coastal Plain, extending from Santa Monica to the hills southeast of Newport in Orange County. All of this region, except a part of the San Fernando Valley, has been surveyed by the Bureau of Soils, and maps and reports of the same have been published. In the fall of 1900 the first work was done about Santa Ana by J. Garnett Holmes, and the reports and maps were published in the annual report of the Bureau for that year. In the spring of 1901 the San Gabriel Valley was also surveyed by Holmes. In the winter of 1902–3 Louis Mesmer surveyed the Coastal Plain west of the Santa Ana area and a part of the San Fernando Valley. In the early spring of 1904 the San Bernardino Valley was surveyed by Holmes, and the reports and maps of these various areas have been published in the annual reports of the Bureau for the respective years in which they were surveyed.

Each district has peculiar conditions, although the problems of the valleys are quite similar, and the Coastal Plain may be considered as a whole. For the sake of convenience, however, each valley and the Coastal Plain will be considered separately.

SAN GABRIEL VALLEY, CALIFORNIA.

In the report made in 1901 the general conditions of this valley are discussed, so that it will be necessary here simply to give a résumé of a part of this general discussion before proceeding to discuss the specific problems outlined above.

The San Gabriel Valley lies just along and south of the Sierra Madre range of mountains. It is cut off from the Coastal Plain by a long, low range of foothills known as the Coast Range. The San Gabriel River, which rises in the Sierra Madre to the north, divides the valley into about equal parts and passes through a narrow pass cut through the Coast Range at the southern side of the valley. The rainfall increases rapidly from the southern side of the valley toward the north, where the Sierra Madre Range causes an increased precipitation of nearly 50 per cent; the range being from 10 to nearly 20 inches.

Nearly all the soils of the valley are composed of rather coarse material, constituting the wash from the granitic mountains on the north. Because of the loose, porous nature of the soils much loss by seepage occurs in the irrigated fields, and much of the water of the San Gabriel River and the numerous small streams that come down from the mountains seeks underground passage through the valley. The only outlet for this seepage water is through the San Gabriel River pass in the Coast Range. This pass is very narrow, so that the seepage water is forced near the surface over quite a large area in the southern part of the valley. During the rainy season much of this low, swampy land has received floodings until recent years, when dikes were constructed and the lands have since been used for truck farming.

At the time of the survey in 1901 a few alkali spots were beginning to show throughout these moist lands, but in no case was the total percentage for the surface 6 feet sufficiently high to kill ordinary crops. The greatest damage done by either the seepage water or alkali had occurred in some of the early walnut groves, which had been injured by the rise of the water table and a consequent "drowning" of the roots. Where the water comes so close to the surface that drains of economical installation will lower and control it such drains will be of great value. As soon as alkali menaces the crops grown arrangements should be made to raise water by pumping, and the whole surface should be heavily flooded. It may be possible to construct ditches to utilize flood waters, which, if of frequent occurrence, would tend to wash out the accumulations of salts. In the northern part of the valley the rainfall is probably sufficient to wash out the surface accumulation that comes from furrow irrigation.

On the whole, the valley was remarkably free from alkali and damage from shallow water table. The southern part of the valley and a small area near Pomona were the only affected districts. Occasional surface flooding and possibly a small amount of drainage are all that is necessary to maintain the conditions existing at the time of the survey.

SAN BERNARDINO VALLEY, CALIFORNIA.

The soil survey of San Bernardino and a part of San Jacinto Valley was made in the early spring of 1904. In this survey only a small number of alkali areas were encountered. The soils and climate of the area are very similar to those of the San Gabriel Valley.

Prior to irrigation a large area of land near Chino, in the San Bernardino Valley, was continually moist and swampy, being occasionally overflowed by small streams from the mountains on the north. Since irrigation began many wells have been sunk in the gravel to the north, and all the streams have been diverted, rendering these swamp lands sufficiently dry for cultivation. Wells have been put down to develop water for the land that was originally a swamp, and now many acres are irrigated. Irrigation on the high land above Riverside has caused some of the land in that colony to be swamped and the citrus trees to be killed. The total acreage, however, that has been thus affected by swamping is very small. The major part of the seepage reaches the deep cut of Santa Ana River in the form of springs, and does no damage to crops.

In San Bernardino proper the only problems thus far arising are to reclaim and prevent the spread of alkali lands near Chino and to make useful the land damaged by seepage in Riverside. The problem near Chino may be solved simply by securing water and flooding heavily the lands showing damage from alkali. The seepage lands in Riverside should be drained and sown to alfalfa or truck crops. One or two heavy floodings will be sufficient to wash out such accumulations of alkali as have occurred since the seepage water killed out the orange trees.

In the San Jacinto Valley there are some quite large areas of alkali lands. Pumping is quite general in the valley and has already resulted in the water table being generally lowered. This pumping is the only available source of water for irrigation, and if it be extended to furnish water to irrigate the alkali land the water table will be sufficiently lowered to cause little damage. Heavy floodings should reclaim the land from alkali and permit the growing of such crops as are suited to the valley.

SAN FERNANDO VALLEY, CALIFORNIA.

When the Los Angeles sheet was surveyed in 1903, a small part of the San Fernando Valley was included, but no alkali was encountered. This valley is almost entirely free from alkali, and extended pumping operations that are being prosecuted will no doubt keep the water table below the danger point.

COASTAL PLAIN OF SOUTHERN CALIFORNIA.

The Coastal Plain proper of southern California is included in the quadrangle of which Los Angeles, San Pedro, and Newport Bay form three corners, the fourth being about 5 miles east of Santa Ana. It is bounded on the southwest by the Pacific Ocean; on the northeast by the Coast Range of hills, which also divides it from the valleys described above, and on the southeast and northwest by spurs of the Coast Range which extend to the ocean. The climate is semiarid and semitropical. The rainfall is sufficient in normal years to grow fair crops of winter grain without irrigation, and for irrigated crops is a great aid in washing down surface accumulations of alkali and starting the crops when sown. The soils, except in the immediate vicinity of the Coast Range and other hills, are alluvial, having been deposited from the waters of the San Gabriel, Santa Ana, and Los Angeles rivers. As a rule they are leachy, sandy, and easily cultivated, the exceptions being the silt loams and adobes, the latter coming principally from the weathering of shales in the Coast Range.

Water for irrigation comes from the above-named rivers and a few small creeks, from pumping, and from artesian wells. Extending along the coast is an artesian belt. Land in this belt was kept continually moist even before irrigation began by springs and overflow waters from the rivers. Since the settlement of the region the greater part of the water of the rivers has been diverted at higher levels for irrigation, and a few drainage ditches have been installed in this moist area. Nearly all the land has thus been reclaimed from its swampy condition and planted. Prior to any agricultural activities there were alkali areas surrounding the swamps and in the places affected by tides. Before being cleared the annual floods washed the lands, and a dense growth of vegetation prevented excessive evaporation from the surface. After having been cleared and cropped, the lands have been left for a part of each year in a barren condition, and subirrigation has been the principal source of supply of moisture. Irrigation on the higher lands has brought the ground water nearer the surface over all the lands surrounding the once swamped area, with a consequent increase of the subirrigated area. As in all cases where subirrigation is practiced, the tendency has been toward the accumulation of alkali at the surface. In this way hundreds of acres of vines and fruit trees that were planted near the swamp lands in the early history of the country have been killed. As irrigation has been extended to the higher lands the water table, because of local subformations, has been in some instances raised to such an extent that older deep-rooted trees have been injured by the rise of the water table. The English walnut is largely grown upon the sandy Coastal Plain soils. In such soils, if there be nothing to prevent, this tree sends its roots to great depths and is the first to suffer from a rise of the water table. Trees have been noted that were suffering with the water table 12 to 15 feet below the surface. Trees planted upon soils having a permanent water table much nearer the surface than this are not injured, so that new orchards planted upon the areas affected, which will adjust their root systems to the high water table conditions, may be very successful where the old trees have died.

The development of sufficient water to flood all subirrigated lands and the extension of the present drainage ditches to reach all lands that have such a high water table as to be cut by the ditches would rid the soil and subsoil of surplus water. A few heavy floodings, after thoroughly leveling the lands, and the exercise of care to prevent evaporation from the surface should sufficiently sweeten the lands to permit the growing of profitable crops. Persistent flooding and careful cultivation should then keep the lands sufficiently free from alkali to permit continued cultivation on a profitable basis.

Alkali found on the Coastal Plain is nearly all of the white variety, principally the sulphate and chloride of sodium. Near the coast on lands affected by tides the chlorides predominate, while farther back the greater part of the alkali is composed of the sulphates.

GRAND FORKS AREA, NORTH DAKOTA.

The survey of the Grand Forks area was made during the field season of 1902, by Charles A. Jensen and N. P. Neill. The area is situated in Grand Forks County, one of the eastern tier of counties of North Dakota, and covers an area of 314 square miles. The area comprises part of the Red River Valley. The annual rainfall is approximately 20 inches, usually so distributed as to furnish moisture for crop purposes during the growing season. Occasionally, however, a season of drought occurs, when crops are practically a failure. The surface of the country is generally quite level, with few marked benches or terraces. Much of the area comprises a portion of the former glacial Lake Agassiz. The soils are mainly sandy loams, gravelly loams, and clay loams composed of slightly modified lacustrine deposits, although there are some soils that have been derived from the glacial drift surrounding former Lake Agassiz. Shallow wells generally contain less soluble salts than the deeper, and especially the flowing wells. The flowing wells contain from 420 to 1,430 parts of soluble salts per 100,000 parts of water, the salts consisting mostly of chlorides, with sulphates next. The deep and flowing wells generally contain less bicarbonates than the shallow wells.

In this area there is generally enough precipitation to prevent the salt in the subsoil from lodging permanently in the surface soil through capillary action, and the roots of crops commonly grown perhaps never reach deeper than 3 feet. Since irrigation is not practiced in the area, the vertical distribution of the salts is not affected artificially, and as long as the present method of farming continues there seems no probability that the salts in the subsoil will rise. In the lighter, well-drained soils there is practically no alkali to a depth of 6 feet. Injurious quantities of alkali were found in the Miami black clay loam and in the Fargo gravelly loam where it occurs in the valley proper. In the first 3 feet of these soils the average amount of alkali is more than 0.20 per cent, with even more in the first 6 feet. The worst alkali conditions were found in the northeastern part of the area. This includes most of the strictly lacustrine deposit soils. Two theories are suggested to account for the origin of the alkali. It may have reached the surface by the capillary movement of the salt-carrying deep-seated waters percolating the underlying drift or cretaceous shales, assisted by the natural pressure to which these substrata are subjected; or it may have been deposited with the lacustrine material by being in solution in the lake water or as being originally in the soil washed into the lake. Since it does not appear that the lake water ever reached a high state of concentration, the latter theory can probably be rejected.

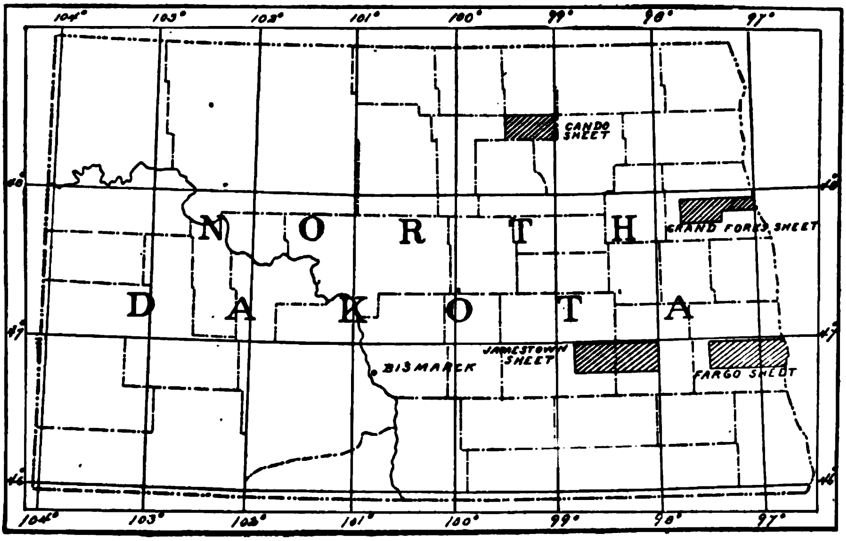

FIG. 7.—Sketch map showing location of areas in which alkali has been studied in North Dakota.

Sulphates largely predominate, with some chlorides, but not in large quantities. With but few exceptions the quantity of salt was found to increase downward. The maximum found was about 3 per cent in the dry soil, and in the worst alkali districts this quantity was found at from 3 to 6 feet. Black alkali was found, even in the presence of small amounts of sulphates, in both soil and subsoil.

Good crops of grain, flax, and millet were often found growing on alkali soils, even where the average amount of salt in the first 3 feet ranged from 1 to 3 per cent. This was due to the unequal vertical distribution of the alkali—the surface foot carrying but a small proportion of the total amount.

The following table, while not intended to define the exact salt conditions under which crops will or will not grow, shows at least conditions as found in the Grand Forks area:

Condition of growing crops in presence of different quantities of alkali.

Crops.	Condition.			
	Good crop.	Fair crop.	Poor crop.	Killed.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Wheat	0.30	....	....	0.56
	.39	....	....	.76
	.46	....	....	....
Oats	.39	0.58	0.63	....
	.46	....	.84	....
	.51	....	....	....
Barley	.31	.44	.70	....
	.43	.46	....	....
Flax	.32	.37	.52	.50
	.38	.55	.64	.86
Prairie and salt grasses	1.16	1.50	....	....
	1.20	2.00	....	....

There are of course different crop conditions with the same salt content in the surface foot of soil, as many factors enter into the discussion, such as late or early seeding, presence or absence of favorable amounts of moisture in the soil, etc. It should also be kept in mind that in every instance the salt content increased in lower depths, the third foot carrying more than 1 per cent of alkali in cases where good crops were growing.

To reclaim these lands they must be drained artificially, as the subsoil is too heavy to accomplish drainage otherwise. Under the present agricultural conditions it is doubtful if the expense involved in reclamation would be justified. Even in their present condition the alkali flats are valuable, as the native grasses growing on the greater part of them make very good hay when properly cured.

In the following table are shown the results of chemical analyses of a number of alkali soils and crusts:

Chemical analyses of alkali soils and crusts.

Constituent.	7460. ¼ mile E. of University; alkali crust.	7461. ¼ mile W. of NE. corner sec. 12, T. 151 N., R. 51 W., alkali crust.	7462. ¼ mile W. of NE. corner sec. 12, T. 151 N., R. 51 W., subsoil 12 to 36 inches.	7463. ½ mile S. of NW. corner sec. 6, T. 151 N., R. 50 W., subsoil 4 to 6 feet.	7464. ½ mile E. of SW. corner sec. 22, T. 151 N., R. 50 W., alkali crust.	7465. ¼ mile S. of NW. corner sec. 10, T. 151 N., R. 50 W., alkali crust.	7466. West center sec. 31, T. 150 N., R. 55 W., subsoil 12 to 36 inches.
Ions:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Calcium (Ca)	6.74	5.83	16.82	13.31	1.76	7.34	24.56
Magnesium (Mg)	14.34	10.74	7.12	5.89	.81	14.24	1.55
Sodium (Na)	1.13	10.69	1.15	1.96	28.44	1.13	.94
Potassium (K)	1.42	.95	2.88	11.44	1.00	.59	1.55
Sulphuric acid (SO_4)	73.94	47.12	59.71	41.93	65.49	73.99	68.94
Chlorine (Cl)	.77	23.59	9.16	20.11	.64	1.56	.64
Bicarbonic acid (HCO_3)	1.66	1.08	3.16	5.36	1.86	1.15	1.82
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	22.28	19.82	57.10	26.45	5.97	24.97	83.46
Magnesium sulphate ($MgSO_4$)	70.99	41.49	24.31	29.22	4.04	70.64	9.99
Sodium sulphate (Na_2SO_4)	2.55	....	....	....	85.91	....	2.35
Potassium chloride (KCl)	1.63	1.81	5.50	21.81	1.35	1.71	1.36
Sodium bicarbonate ($NaHCO_3$)	1.09	1.49	4.29	....	1.99	1.58	.72
Magnesium chloride ($MgCl_2$)	....	9.24	8.80	....	....	....	....
Sodium chloride (NaCl)	....	26.15	....	....	....	1.70	....
Calcium chloride ($CaCl_2$)	....	....	....	15.19	....	....	....
Per cent soluble	10.79	15.50	3.82	2.24	12.96	12.52	5.27

BILLINGS AREA, MONTANA.

This area comprises about 107 square miles and was surveyed in 1902 by C. A. Jensen and N. P. Neill. Preliminary investigations were carried on near Billings in 1897 by Prof. Milton Whitney, while in 1898 Thomas H. Means made a study of the alkali and seepage waters of a section of land west of Billings. The results of the latter investigation were published in 1898 as Bulletin No. 14 of the Bureau of Soils under the title "The Alkali Soils of the Yellowstone Valley." The results of this earlier work will be included with the discussion of Jensen's report.

The area includes part of the Yellowstone Valley in the south-central part of eastern Montana. The valley consists of level areas, with higher terraces or benches bounded on each side by high continuous bluffs of cretaceous sandstone and shale.

The climate is semiarid, the valley having an annual rainfall of about 12 inches. This is not sufficient to grow crops, but materially aids irrigation. Agriculture was not extensively carried on until the building of the Northern Pacific Railroad in 1882. Since that time the development of the agricultural interests has been quite rapid.

The soils consist of clays, loams, and sandy and gravelly loams, with the heavy soils predominating. The soils are derived from the weathering of the Fort Benton shales and sandstones, modified and deposited by river action.

During the field work a large number of well, drainage, and spring waters were examined. All the samples contained a considerable quantity of salts in solution. The well waters were particularly impure, the salt content varying from 170 to 900 parts in 100,000 parts of water. From the examination it was found that the subsoil water is quite generally impregnated with alkali. The wells having the highest salt content are located in the level clay areas, where the soil texture is heavy to some depth, and in the alkali areas, where the subsoil water is near the surface. The better wells are located on or near the gravel terraces, as would be expected, the underdrainage there being comparatively good. Some of the springs found along the river bank and below the gravel terrace were much better than the wells, but as a general rule were too salty for use. This condition of the subsoil and drainage waters indicates forcibly both insufficient underground drainage and the existence of accumulations of salt in the subsoil. Such strongly alkaline solutions could hardly exist in all the wells were the underground drainage good, and the springs would not be so generally salty were there no accumulations of salt in the deep subsoil.

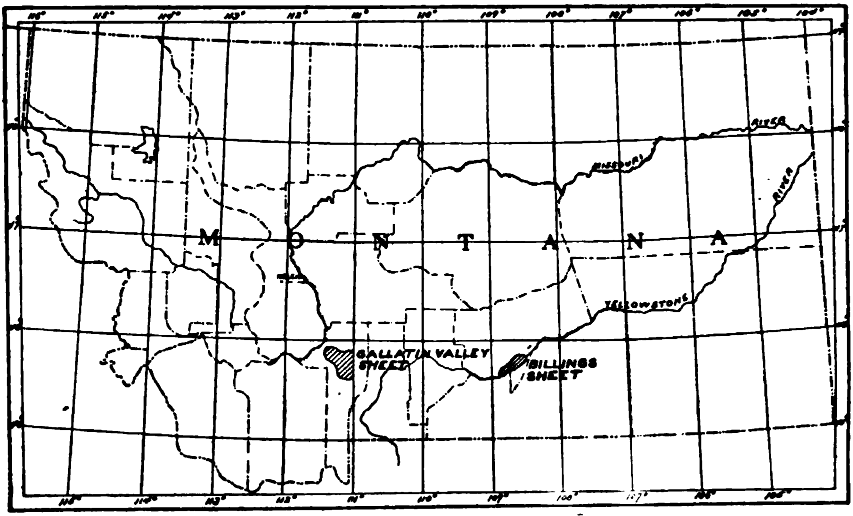

FIG. 8.—Sketch map showing location of areas in which alkali has been studied in Montana.

In the following table is shown the analysis of a sample of drainage water collected from about 2 miles southwest of Billings:

Constituent.	Per cent.	Constituent.	Per cent.
Ions:		Conventional combinations:	
Calcium (Ca)	7.11	Calcium sulphate ($CaSO_4$)	24.16
Magnesium (Mg)	4.84	Magnesium sulphate ($MgSO_4$)	24.01
Sodium (Na)	15.85	Potassium chloride (KCl)	1.92
Potassium (K)	1.01	Sodium chloride (NaCl)	2.23
Sulphuric acid (SO_4)	62.17	Sodium bicarbonate ($NaHCO_3$)	9.29
Chlorine (Cl)	2.26	Sodium carbonate ($NaCO_3$)	38.39
Bicarbonic acid (HCO_3)	6.75		
		Total solids, parts per 100,000	681.5

The greatest quantity of alkali was found in the heavy clay and loam soils. Alkali was not found, however, in all of the clay soils, as some have a light subsoil which gives good underdrainage. But wherever the clay extends to a depth of 6 feet or more, alkali is found. The vertical distribution of the alkali varies, being governed by the texture of the soil and subsoil and the position of the underground water. In virgin alkali clay areas the distribution is quite uniform below the first foot, with the maximum at about 5 feet below the surface. In deep clay areas, where irrigation has been moderate and well managed, the maximum salt content is from the third to the sixth foot. On some of the bench lands and on the alkali soils along the river the maximum amount of alkali is found in the first or second foot, with generally an accumulation on the surface due to evaporation of subsoil water, which is near enough to the surface to be raised by capillarity. In the irrigated soils along the canals the amount of alkali in the first 6 feet is usually less than 0.20, and generally increases downward. In one place where a heavy growth of greasewood was seen no injurious quantities of salts were found until the twelfth foot was reached. From there down to the sixteenth foot the soil was moist and carried considerable quantities of sulphates.

The source of the alkali found in the upper bench land and most of that in the level area south of it is the shales underlying the sandstones on the north side of the valley. The sandstone beds have also contributed a little, but by far the most of it came from the underlying shale. Exposures of this shale in the hills are usually covered with a deposit of salt, and many smaller beds and veins of salt—mostly calcium sulphate—were found in such places. The origin of the alkali in some of the river-deposited sandy loams is mostly in the seepage water coming from the bench lands.

The composition of the alkali in the bench soils is quite uniform, consisting principally of sulphates, with small amounts of bicarbonates, chlorides, and some traces of alkaline carbonates. In boring samples sulphates were found in both the amorphous and crystalline forms, these having separated after the deposition of the soil or having been transported as such with the soil.

A notable feature in the composition of the alkali in the Billings area is the remarkably small amount of hydrogen carbonates present. This accounts for the small quantity of normal carbonates or black alkali encountered. Moreover, there seems to be none in the shales from which the alkali originated. Probably the reason for such small quantities of bicarbonates is due to some extent to the large amounts of sodium sulphate present, which, according to work done in the Bureau laboratories, drives back the bicarbonates to the normal carbonates. The probable result in the soil would be the formation of lime carbonate.

It is of interest to compare some of the alkali conditions as they existed in 1898, the time of the first examination, and in 1902, the time when the soils of the area were studied. The following table gives data for such a comparison:

Table showing alkali conditions of the soil in 1898 and 1902.

DETERMINATIONS MADE IN 1898.

No. of boring.	Location.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
65	¾ mile W. of NE corner sec. 1, T. 1 S., R. 25 E.	0.57	0.49	0.34	....	([a])	([a])
66	¾ mile W. of NE. corner sec. 1, T. 1 S., R. 25 E.	.64	.38	.31	0.34	([a])	([a])
33	¼ mile W. of SE. corner sec. 2, T. 1 S., R. 25 E.	.19	.24	.44	.46	0.46	0.31
34	S. center sec. 2. T. 1 S., R. 25 E............	.70	.52	.41	.32	.32	.27
40	S. center sec. 5, T. 1 S., R. 26 E............	.35	.89	.23	.17	.20	....
11	Center NE. ¼ sec. 4, T. 1 S., R. 26 E.........	.10	.51	.28	.17	....	....
12	⅛ mile NW. of center sec. 4, T. 1 S., R. 26 E....	.32	.41	.41	.47	....	....

DETERMINATIONS MADE IN 1902.

		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
62	¼ mile W. of NE. corner sec. 1, T. 1 S., R. 25 E	2.20	1.24	0.66	0.58	....	0.66
67	¼ mile W. of SE. corner sec. 2, T. 1 S., R. 25 E.	.54	.41	.51	.60	0.52	.40
69	S. center sec. 2, T. 1 S., R. 25 E............	3.00	....	.45	....	.37	....
12	S. center sec. 5, T. 1 S., R. 26 E............	.93	.56	.40	.30	....	.36
29	Center NE. ¼ sec. 4, T. 1 S., R. 26 E.........	.60	....	.25	....	.42	....
30	⅛ mile NW. of center sec. 4, T. 1 S., R. 26 E...	2.50	2.35	1.35	.98	1.20	....

[a] Not determined.

As the method of determination—by means of the electrolytic bridge—was the same in both instances, these borings can be compared quite safely. It will be seen that the conditions in places were much worse in 1902 than in 1898, as regards both salt on the surface and in the subsoil.

The following table shows the analyses of the standardization crusts and solution. Sulphates predominate, principally of sodium, the latter constituting from two-thirds to three-fourths of the total. Chlorides are not present in large quantities, and estimable carbonates occur in only two crusts.

Chemical analyses of crusts used in standardization.

Constituent.	6600. Near NW. corner sec. 2, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6601. Center sec. 10, T. 1 S., R. 26 E., soil 0 to 10 inches.	6602. Center sec. 10, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6603. S. center sec. 9, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6604. Center sec. 8, T. 1 S., R. 26 E., crust 0 to 1 inch.	6605. W. center sec. 34, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	0.79	2.99	0.16	3.63	4.14	1.85
Magnesium (Mg)	1.79	.85	.24	2.01	2.57	2.95
Sodium (Na)	28.16	20.56	31.73	23.51	22.06	25.03
Potassium (K)	.72	9.63	.88	2.78	2.79	1.08
Sulphuric acid (SO_4)	67.73	45.85	59.93	62.98	61.06	66.49
Chlorine (Cl)	.33	Trace.	1.48	3.24	4.70	1.54
Bicarbonic acid (HCO_3)	.48	16.06	2.83	1.85	2.68	1.06
Carbonic acid (CO_3)	Tr.	4.06	2.75	....	....	....
Conventional combinations:						
Calcium sulphate ($CaSO_4$)	2.71	10.07	.55	12.29	14.00	6.08
Magnesium sulphate ($MgSO_4$)	8.90	4.06	1.22	9.91	12.76	14.58
Sodium sulphate (Na_2SO_4)	85.57	35.12	85.06	66.66	55.68	72.93
Potassium sulphate (K_2SO_4)	1.60	21.41	1.96	6.18	6.15	2.41
Sodium bicarbonate ($NaHCO_3$)	.67	22.06	3.90	2.55	3.69	1.46
Sodium carbonate (Na_2CO_3)	Tr.	7.28	4.87	....	....	....
Sodium chloride (NaCl)	.55	Tr.	2.44	5.41	7.72	2.54
Per cent soluble	44.68	0.934	17.00	2.59	1.79	9.04

Chemical analysis of standardization solution.

Constituent.	Per cent.	Constituent.	Per cent.
Ions:		Conventional combinations:	
Calcium (Ca)	0.89	Calcium sulphate ($CaSO_4$)	3.03
Magnesium (Mg)	1.83	Magnesium sulphate ($MgSO_4$)	9.06
Sodium (Na)	26.24	Potassium sulphate (K_2SO_4)	8.14
Potassium (K)	3.65	Sodium chloride (NaCl)	2.91
Sulphuric acid (SO_4)	63.68	Sodium carbonate (Na_2CO_3)	1.45
Chlorine (Cl)	1.76	Sodium bicarbonate ($NaHCO_3$)	1.56
Bicarbonic acid (HCO_3)	1.13	Sodium sulphate (Na_2SO_4)	73.85
Carbonic acid (CO_3)	.82		

As much of the area, especially the clay soils, was originally charged with alkali, the blame for the present serious conditions can not be laid wholly to seepage resulting from irrigation of the higher lying lands. Seepage and drainage waters are, however, doing considerable damage, for, as a rule, the alkali areas where standing water is within 6 feet of the surface have an accumulation of salts.

The following table shows the areas of alkali lands in the survey around Billings:

Area of alkali lands, Billings, Mont.

Alkali.	Sq. miles.	Acres.	Per cent.
Less than 0.20 per cent	67.1	42,944	62.7
From 0.20 to 0.40 per cent	13.5	8,640	12.6
From 0.40 to 0.60 per cent	15.6	9,984	14.6
From 0.60 to 1 per cent	8.7	5,568	8.1
From 1 to 3 per cent	2.1	1,344	2.1
Total	107.0	68,480	....

The first step in the reclamation of these lands is to lower the subsoil water. The question resolves itself into one of underdrainage. Some small attempts at reclamation have been made by digging shallow ditches, but these soon filled, and little benefit was derived from their use. The subject of reclamation of lands in this area will be referred to in the chapter on the reclamation of alkali lands.

WALLA WALLA AREA, WASHINGTON.

This area occupies the south-central part of Walla Walla County and was surveyed in 1902 by J. Garnett Holmes. The climate of the country is semiarid, the annual rainfall being 17.7 inches. The climate is excellent for the growth of cereals, fruits, and vegetables. The surface of the country is rolling, with no level areas except along the small streams. Irrigation is only practiced in these small valleys, as the hills are too rough to make possible any method of applying water. The soils consist mostly of sandy loams and light silty loams that have been derived from lacustrine deposits mixed with considerable quantities of volcanic ash.

Toward the western part of the area, along the Walla Walla River and Mud and Dry creeks, the land contains alkali, some of it so much as to be practically abandoned. Even in the small valleys about Walla Walla and in some places on hillsides patches of alkali are seen, but such patches are small in extent, and the percentage of alkali present in the soil is very low.

All of the soil of the valley has traces of alkali. Those areas where the quantity is harmful are due to the localizing and concentration of the alkali by the water, which takes up a small quantity of salt and deposits it at the point of evaporation. Thus an accumulation of alkali is the usual accompaniment of a high water table. Small alkali patches at the base of hills are caused by the seepage from rain water, which soaks into the hills, dissolves the easily soluble salts, and then in part slowly seeps out and is evaporated, leaving the alkali on or near the surface.

The alkali is nearly all carbonate and bicarbonate of sodium. While the total salts in the surface 6 feet rarely exceed 0.20 per cent, there is quite an area in the western part of the district, along the Walla Walla River, where the surface 3 feet contains more than 0.20 per cent of black alkali alone.

Only a small part of the area surveyed contained enough alkali to be impaired for agricultural uses. Five one-hundredths per cent in the soil from which the plants feed is enough materially to injure sensitive crops like wheat and many of the vegetables. Barley will do fairly well on such land, and alfalfa, if once well established, will grow, though it will not thrive. Pears and apples are affected, but will live. As this quantity is increased, however, the list of plants that may be grown rapidly diminishes until, when the concentration reaches 0.10 per cent, none of the crops of the valley will grow. All lands containing more than 0.10 per cent must be reclaimed before crops can be grown.

There is no alkali land in the area that can not be economically reclaimed. It is all situated in the small valleys along streams and when under cultivation and free from alkali is the most valuable soil in the county. The soils are all of such an open and porous nature that alkali may readily be washed from them, and the numerous small streams that intersect the area are usually far enough below the level of the valley to afford good outlets for drains. These same streams afford ample and excellent water for irrigating all the land contained in the valleys. The present condition of the alkali areas is due either to neglect or to improper treatment in cultivation. The most efficient method for reclaiming the land is to remove the alkali in the way it was accumulated—that is, through the action of water. If the land was continuously cultivated, or a mulch maintained in some other way, the rainfall would in the course of a few years reclaim the areas that are now only partially damaged. But since water for irrigation can be obtained so readily and cheaply the rainfall should be augmented by irrigation.

LOWER ARKANSAS VALLEY, COLORADO.

This area, surveyed by Macy H. Lapham and party in 1902, lies in southeastern Colorado. It embraces large areas in Otero, Bent, and Prowers counties, and is traversed from west to east by the Arkansas River. This area is one of the most important agricultural sections of the State, and is watered by some of the most extensive storage-reservoir and canal systems of the arid West. Its soils are famed for their fertility, and the Arkansas Valley is known for its stock-feeding industries and for the production of alfalfa, sugar beets, melons, fruits, and vegetables. The area surveyed has an extent of 945 square miles.

The area receives an annual rainfall of about 13 inches. The surface features of the area consist of the Arkansas Valley proper and the uplands. The latter consist of a succession of smooth, even, gently undulating prairies characteristic of the Great Plains, broken in places by arroyos with vertical sides, and traversed by streams of a more or less intermittent flow. The Arkansas Valley proper forms a trough from 2 to 5 miles wide, and from 100 to 300 feet deep, carved out by the river. Prominent bluff lines mark its borders through much of the valley. At other points more gradual slopes prevail, with minor terraces of gravel, sand, heavy silt, and clay deposits. The soils naturally fall into two divisions—the valley soils consisting of a complex mass of sands, gravels, and clays deposited by the river, and the generally deep upland soils derived from the breaking down of sandstones, shales, and limestones. All waters taken from the Arkansas River and its tributaries show a considerable quantity of soluble mineral salts, but these are generally of the less harmful class. With proper cultivation and drainage no harmful results should follow their use.

The source of the artesian water of the Arkansas Valley is the Dakota sandstone. These rocks outcrop over large areas in the vicinity of the mountains, where the main supply is received. The character of the waters also varies considerably, all of them being mineralized to a greater or less extent, depending upon the quantity of the infiltrating waters from the cretaceous shales, which are heavily charged with the alkali salts. Analyses of these waters show the main salts to consist of sodium bicarbonate, sodium sulphate, and magnesium sulphate. The quality of the ground water as a whole is poor and it is often unfit for domestic use. The surface wells are often contaminated by organic matter and surface drainage, and the waters are usually too highly charged with alkali salts to be used for drinking purposes. Upon the uplands of the Arkansas Valley and above the canals the water table lies at relatively great depths. Near the canals, however, and through the valley bottoms it appears very near the surface. While the damage from the accumulation of alkali and seepage waters in the valley is much less than in many sections of the arid West, it is sufficiently serious to cause alarm. The greatest

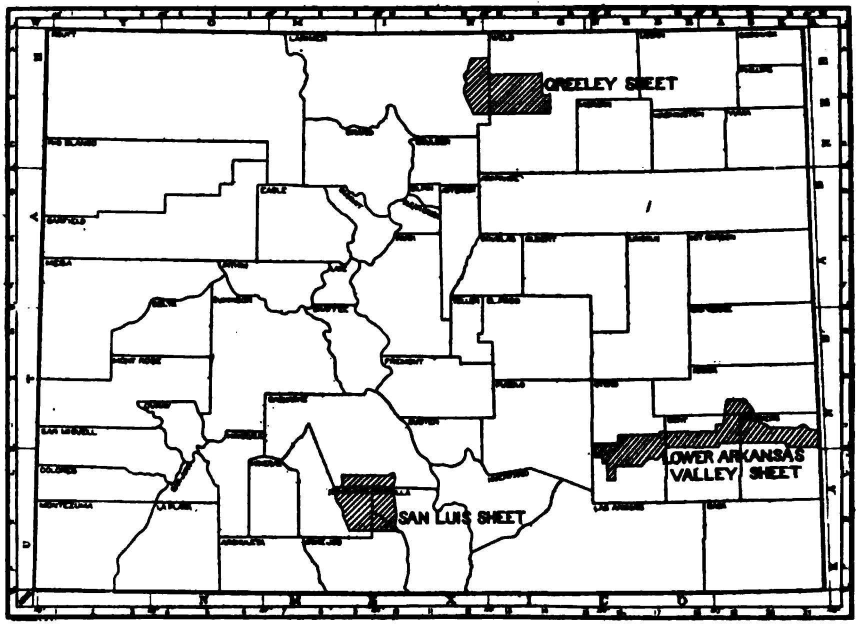

FIG. 9.—Sketch map showing location of areas in which alkali has been studied in Colorado.

injury has occurred in the bottoms of the main valley and of the many tributary valleys extending outward from it. In the western part of the area the local depression known as Patterson Hollow is one of the worst affected areas. Eastward from this point many parts of the bottoms show similarly bad conditions. Springs carrying a considerable quantity of alkali-laden seepage water are frequent, and many local sloughs and bogs have been formed since the advent of irrigation. In nearly all these localities the conditions seem to be rapidly growing worse and means should be taken at once to put a stop to the evil.

All of the seepage water contains large quantities of alkali salts, the sulphates and carbonates predominating. Black alkali has been detected, but exists only in small proportions. The salts in the seepage water are derived from the leaching of the cretaceous shale rocks and adjoining soils. Analysis of the cretaceous shale shows large quantities of sodium bicarbonate, calcium sulphate, calcium chloride, and magnesium chloride.

In nearly all cases it was found that wherever there is a concentration of 0.20 per cent or more of alkali in the first 6 feet of soil the water table was found 6 feet or less from the surface. This relation shows the effect of the seepage waters upon the distribution of the alkali salts in the soils and the accumulation of alkali upon the surface.

In the uplands the soils damaged by alkali occur as relatively narrow strips running parallel with the canals or as broader bodies occupying local draws, flats, or former seepage lake bottoms.

In the valley proper the damaged areas usually occur upon the heavier soils of the bottoms. In the southeastern part of the survey several alkali areas covering creek bottoms contain from 0.20 to 1 per cent of alkali in the first 6 feet, having the greater proportion of all the salts in the subsoil. The surface soil is free from alkali or nearly so. In this condition the lands, although heavily charged with alkali, will produce good crops until the alkali of the subsoil is brought to the surface by irrigation and seepage waters.

Sodium sulphate is the prevailing alkali salt of the area. This, with other common salts, is derived largely from the cretaceous shales. Sodium chloride is second in quantity and importance, while calcium sulphate, or gypsum, and magnesium sulphate form large proportions of the remaining alkali salts of the region. Sodium bicarbonate is generally found, often in considerable quantities, in the irrigation and seepage waters, but the injurious sodium carbonate does not exist in harmful quantities in either the soil or irrigation waters. This salt has been detected in solution in seepage waters of poorly drained areas, where it probably owes its formation to conversion from the bicarbonate through deficient drainage, which favors this chemical reaction.

Under normal conditions the alkali salts of the valley occur only in the subsoil, the rainfall being sufficient to leach them from the immediate surface. With irrigation the subsoil becomes filled with water and the water table of the lower lying lands is raised. As the irrigation and seepage waters percolate through the soil, the readily soluble salts are leached away and carried to the lower lands, and there, by the evaporation of these waters, the dissolved material is left upon the surface as an alkali crust.

Several methods for the reclamation of alkali lands have been tried in this area. Prominent among these are the removal of alkali crusts by scraping, washing away of the surface concentrations by heavy flooding, the cultivation of alkali-resistant crops, and the application of gypsum. All of these may under certain conditions be of value in aiding the removal of the alkali salts, but for the reclamation of lands containing any considerable quantities of alkali all are inefficient.

Several examples of tile drainage and its effects may be seen in this area at the present time. At the time the survey was made, in 1902, these systems had only been in use a few months, but the results were very gratifying, especially upon the lands of the American Beet Sugar Company at Rockyford. The system during the summer of 1902 resulted in lowering the water table from 1 to 2 feet.

YUMA AREA, ARIZONA-CALIFORNIA.

In the early part of 1902 a soil survey was made of the valley lands below Yuma, the soil and alkali maps and report being published in the Field Operations of the Bureau of Soils for that year. In the winter of 1903–4 a large party in charge of J. Garnett Holmes was sent to the district to survey and classify all the lands below the Laguna dam site on each side of the river. All of the alkali lands, or those having a high water table, are included in the bottom lands immediately along the Colorado River from Laguna dam site about 20 miles up the river from Yuma to the Mexican boundary line, about an equal distance down the river.

The climate of this region is distinctly arid, the annual rainfall being less than 3 inches. The soils of the valley are nearly all sandy, only small areas of heavy soils being found.

About 60 per cent of the bottom lands receives annually a heavy flooding from overflow waters of the Colorado. These overflow lands are thus washed clear of any salts that may have accumulated during the season and are uniformly free from heavy accumulations of alkali. Along the outer edge of the lands overflowed, however, and on isolated high knolls within the overflowed area, alkali has accumulated. Accumulations have also occurred in places at the foot of the mesa land which bounds the valley, due to seepage from the mesa lands above. All these accumulations may be attributed to the same cause—subirrigation or the lifting of the water to the surface, there to be evaporated and leave behind its small load of soluble salts. With the water table within capillary reach of the surface almost the entire year and greatly raised during the overflow season, at which time the temperature is very high and evaporation enormous, it is small wonder that these lands contain large amounts of alkali. The fine sandy loam soil, because of its great capillary power and slight resistance to the passage of water through it, is always the soil containing the greatest quantity of salts.

The diking and draining of the overflow lands, and the installation of sufficient drainage for the nonoverflow lands not yet irrigated, are problems for the experienced engineer and are being carefully considered by the engineers of the Reclamation Service. But what of the actual reclamation of alkali lands? This question has been answered by the experience of the settlers. When the lands below Yuma were settled and irrigation began, many acres were heavily charged with alkali. These lands were leveled and heavily flooded, until now some of the best alfalfa fields in our irrigated regions are found on these lands once heavily impregnated with alkali. The whole country is underlain by sand, which allows the percolation of ground water into which the salts are washed. There can be no question that the flooding in irrigation and care in cultivation will reclaim the lands already filled with alkali and prevent the other lands from becoming filled if there be sufficient drainage to prevent swamping.

The alkali here is of the white kind. Following is a table giving a number of analyses of alkali crusts and soils:

Chemical analyses of salts in alkali soils.

Constituents.	6501. SW. corner No.2–40, sec. 25, T. 8 S., R. 24 W.; fine sandy loam, 0 to 72 inches.	6506. SE. corner No. 14–40, sec. 18, T. 9 S., R. 23 W.; sand, 0 to 48 inches.	6504. Near center sec. 2, T. 9 S., R. 24 W.; loam, 0 to 36 inches.	6503. Under No. 6502; clay loam, 36 to 72 inches.	6509. NW. corner No. 1–40, sec. 26, T. 8 S., R. 24 W.; sandy loam, 0 to 72 inches.	6502. Center S. side No. 15–40, sec. 36, T. 8 S., R. 23 W.; loam, 0 to 36 inches.	6511. E. side No. 9–40, sec. 12, T. 9 S., R. 24 W.; sandy loam, 0 to 72 inches.	6517. Center N. side, sec. 27, T. 8 S., R. 24 W.; alkali crust, 0 to 1 inch.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	9.42	5.18	2.72	1.74	9.02	5.27	3.87	2.04
Magnesium (Mg)	2.53	.99	1.27	1.43	4.45	2.49	2.07	1.96
Sodium (Na)	11.23	24.54	27.80	29.25	17.66	25.03	29.29	32.04
Potassium (K)	11.60	4.38	4.17	3.97	3.34	3.58	1.14	2.10
Sulphuric acid (SO_4)	28.26	32.96	18.51	13.68	18.26	14.64	14.07	4.66
Chlorine (Cl)	21.74	22.39	35.73	41.35	43.93	46.36	47.60	56.98
Bicarbonic acid (HCO_3)	15.22	9.56	9.80	8.58	3.34	2.63	1.96	.22
Conventional combinations:								
Calcium sulphate ($CaSo_4$)	32.25	15.34	9.07	5.88	25.83	17.86	13.09	6.61
Magnesium sulphate ($MgSO_4$)	6.88	4.78	6.17	6.99	.00	.00	6.00	.00
Potassium chloride (KCl)	22.10	8.36	7.98	7.63	6.34	6.81	2.18	4.00
Sodium chloride (NaCl)	13.77	30.09	52.71	62.18	41.98	59.17	72.68	81.15
Sodium bicarbonate ($NaHCO_3$)	21.02	13.14	13.36	11.76	4.56	3.58	2.67	.28
Sodium sulphate (Na_2SO_4)	.00	28.29	10.71	5.56	.00	2.85	.00	.00
Calcium chloride ($CaCl_2$)	.00	.00	.00	.00	3.89	.00	.00	.25
Magnesium chloride ($MgCl_2$)	3.98	.00	.00	.00	17.40	9.73	3.88	7.71

Chemical analyses of salts in alkali soils—Continued.

Constituents.	6515. Center S. side sec. 20, T. 8 S., R. 23 W.; alkali crust and mulch, 0 to 1 inch.	6520. Center S. side No. 13–40, sec. 36, T. 8 S., R. 23 W.; alkali crust and mulch, 0 to 1 inch.	6516. NW. corner No. 1–40, sec. 26, T. 8 S., R. 24 W.; alkali crust, 0 to 1 inch.	6525. No. 6–40, sec. 9, T. 10 S., R. 24 W.; alkali crust, 0 to ½ inch.	6526. No. 14–40, sec. 6, T. 10 S., R. 24 W.; alkali crust, 0 to ½ inch.	6522. N. side sec. 33; alkali crust, 0 to 1 inch.	6519. No. 12–40, sec. 36, T. 8 S., R. 24 W.; alkali crust, 0 to ½ inch.	6523. Center of sec. 17, T. 9 S., R. 23 W.; alkali crust, 0 to 1 inch.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	6.56	8.78	5.70	2.35	0.92	1.55	0.87	1.55
Magnesium (Mg)	2.67	3.39	6.76	.45	.28	1.00	.04	.25
Sodium (Na)	26.83	20.81	20.99	28.50	32.70	27.65	37.46	31.49
Potassium (K)	1.22	4.87	2.14	4.24	1.77	4.63	.88	6.50
Sulphuric acid (SO_4)	2.31	1.76	.87	41.82	37.73	20.75	10.64	5.31
Chlorine (Cl)	59.73	59.88	63.09	21.80	26.40	43.94	49.86	53.66
Bicarbonic acid (HCO_3)	.68	.51	.45	.64	.20	.48	.25	1.24
Conventional combinations:								
Calcium sulphate ($CaSO_4$)	3.25	2.50	1.23	7.98	3.14	5.26	2.97	5.28
Magnesium sulphate ($MgSO_4$)	.00	.00	.00	2.23	1.40	4.98	.36	1.27
Potassium chloride (KCl)	2.33	9.28	4.08	8.08	3.39	8.82	1.69	12.39
Sodium chloride (NaCl)	67.50	52.33	52.87	29.65	40.90	60.96	80.72	78.53
Sodium bicarbonate ($NaHCO_3$)	.93	.70	.61	1.15	.27	.66	.34	1.71
Sodium sulphate (Na_2SO_4)	.00	.00	.00	50.91	50.91	19.32	13.92	.82
Calcium chloride ($CaCl_2$)	15.48	21.90	14.70	.00	.00	.00	.00	.00
Magnesium chloride ($MgCl_2$)	10.51	13.29	26.51	.00	.00	.00	.00	.00

The water for irrigation all comes from the Colorado. Analyses of this water show no harmful amount of salts. No damage should be experienced from its use if applied in flood irrigation, or in the case of furrow irrigation on alkali-free lands, if occasional surface smoothings and floodings are given to wash out of the surface the accumulations of salts that must result from this method of applying water. The rainfall in this region is too slight to perform this office, so floodings will be necessary.

BLACKFOOT AREA, IDAHO.

The Blackfoot area was surveyed by W. E. McLendon in 1903. It includes all of the irrigable lands of the Snake River Valley for a distance of 50 miles in Brigham and Fremont counties. The area contains approximately 428 square miles. The annual rainfall amounts to about 9 inches.

The area is practically free from injurious accumulations of soluble salts in the soil. With only two exceptions no alkali was encountered. In these places the water table had risen near the surface and caused the accumulations which occurred at or near the surface. In places the water table was found to be rising, and unless proper precautions are taken more trouble from alkali and seepage waters will be experienced in the future.

SOLOMONSVILLE AREA, ARIZONA.

The Solomonsville area was surveyed in 1903 by Macy H. Lapham and N. P. Neill. The area comprises about 108 square miles and is situated in the southeastern part of the Territory, lying along the valley of the upper Gila River. The climate is essentially arid, the average annual rainfall being less than 10 inches. The Gila Valley is almost wholly inclosed by rugged mountain ranges consisting of granite, with intrusions of volcanic rocks, usually of recent date. The river bottom or valley trough occupies a tract from 1 to 5 miles in width, through which flows the Gila River. From the valley trough the bottom extends outward with a gentle slope to the bluff lines, marking the margins of the mesa lands.

The soils of the area naturally fall into two widely separated divisions, viz, colluvial soils and alluvial soils. The colluvial soils make up the original foot slopes of the mountains and consist of mountain waste deposited in gently sloping plains by intermittent floods from cloud-bursts falling upon the mountain sides. These soils consist of sands, sandy loams, and gravelly loams. The alluvial soils include those formed by river sediments brought long distances in suspension and deposited by floods along the river flood plain. These soils include fine sandy loams, silt loams, and deposits of coarse gravel.

Water was encountered in a few places along the lower valley at a depth of less than 10 feet, but the average depth of wells at the time of the survey was from 20 to 30 feet. In general the well waters of the Gila Valley carry large quantities of soluble salts, many of them being unfit for domestic use. Analyses of well waters showed the presence of considerable quantities of sodium chloride, sodium bicarbonate, and sodium sulphate.

Seepage water was abundant, but had collected to a dangerous extent in only a few localities. This water is accumulated by leakage of canals and laterals or by excessive irrigation of higher lying lands. Water in excess of the quantity required by growing crops percolates downward, fills the subsoil, and finds its way through the more porous substrata to lower levels and local drainage basins. In this way large areas of valuable land at lower levels are damaged, being converted into bogs, marshes, or alkali flats. The effect of this upon the composition and distribution of the alkali salts of the soil is important. Not only does a water-logged soil lead to the formation of alkali salts and their concentration within the zone of root activity, but the excess of water retards aeration and produces harmful changes in the physical structure of the soil. Small bodies of land damaged by seepage water were found along the lower valley level throughout the area. In some cases such areas amount to hundreds of acres.

The alkali of the Gila Valley was found to be confined for the most part to the Maricopa silt loam, a compact and impervious soil formed by material deposited by the Gila River and its tributaries. There were about half a dozen places ranging from one-half mile to 3 square miles in extent where alkali prevailed in dangerous quantities. The proportion of alkali soil as compared with the size of the area surveyed was considerable. Over much of the area containing from 0.20 to 0.40 per cent most of the alkali was in the lower part of the 6-foot section. Alfalfa when once started makes nearly a normal growth, and in some cases does well. In soils where the salt content does not exceed 0.40 per cent, sorghum, sugar beets, and alfalfa may be grown with profit, provided precautions are taken in starting the crop, such as heavy irrigations before planting to start a downward movement of the salts into the subsoil. By the time they return to the surface the crop may have sufficient stand and vitality to endure the injurious effects of the salts.

Sodium chloride was of common occurrence and formed a large proportion of the alkali salts, both in the soils and underground waters. Sodium sulphate also occurred in large quantities, and with sodium chloride formed practically all of the white alkali of the area. Sodium bicarbonate and carbonate also appeared to some extent in the Gila Valley. Sodium carbonate occurred in large and dangerous quantities only in a few small spots. In the Gila Valley area the subsoils of the heavier type carry in the aggregate great quantities of alkali salts. Fortunately, however, irrigation is less frequent than in many western districts. The water table lies at such depth under a great part of the area that the movement of the salts upward takes place only to a limited extent. The accumulation of the alkali salts upon the surface results for the most part from evaporation of irrigating waters carrying in solution the salts derived from percolation of the upper portion of the soil section. The water table plays but little or no part in the accumulation.

LARAMIE AREA, WYOMING.

The Laramie area was surveyed by N. P. Neill and party in 1903. The area lies in the south-central part of Albany County, extending in a southeast and northwest direction along the Laramie River for a distance of about 40 miles. The area is about 8 miles wide and includes approximately 309 square miles. The climate is essentially arid, the annual rainfall at Laramie being about 10 inches. The greater part of the area lies in the Laramie Plains. Since the formation of these plains the river has cut down through them, forming the Laramie Valley proper. The river flows through low banks that slope gradually back to the hills or level uplands, but at a few places there are precipitous bluffs. The uplands are more or less rolling, with an elevation of from 7,300 to 7,500 feet above sea level.

The soils may be divided into three general classes, according to their origin or manner of formation. These are, first, residual soils derived in place from the weathering of rocks; second, alluvial soils formed from the materials deposited by the river; third, colluvial soils formed from material carried from the mountains by transporting agencies.

Sandy loam soils prevail, with smaller bodies of gravelly loams and heavy clay soils. Water for irrigation is taken from the Laramie River and from chemical analyses appears to be of excellent quality.

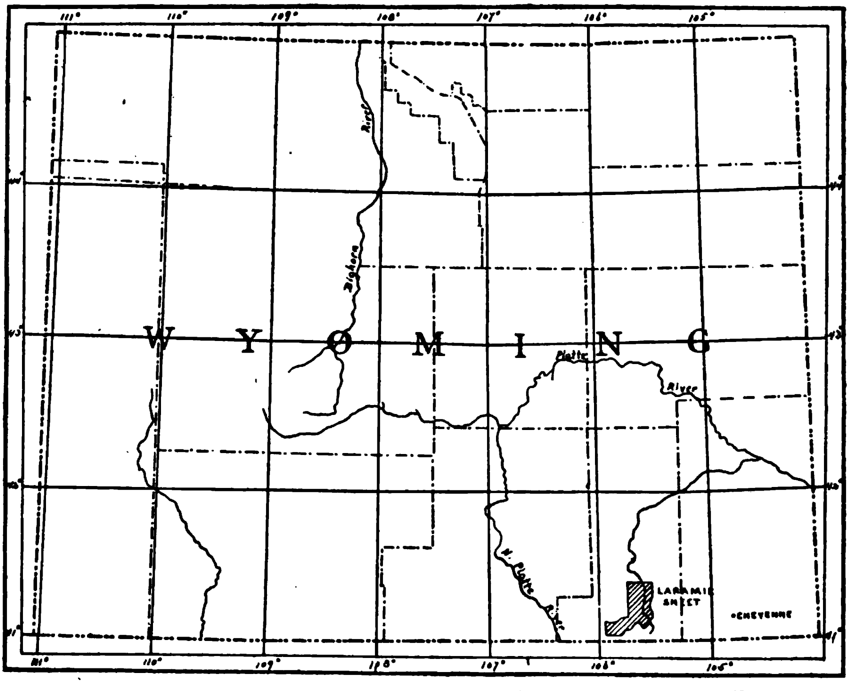

FIG. 10.—Sketch map showing location of areas in which alkali has been studied in Wyoming.

A considerable part of the once productive lands of the Laramie area has been injured by seepage waters. Drainage of these lands would not be difficult, as the fall toward the river is generally sufficient. Analyses of well water and water from the soda lakes show large quantities of sodium and magnesium sulphate, with varying amounts of chlorides. Carbonates occur, but generally in very small amounts.

Most of the alkali found in the Laramie area occurred in the lowlands along the Laramie River. The original source of the alkali is the exposed banks of clay, shale, and sandstone found in and around the area. Surface accumulations may be seen where these clays, shales, and sandstones outcrop. The alkali contained in these deposits is continually leaching out and being stored in the soil already containing a large percentage of soluble salts. Where such land is irrigated or washed by rain waters the alkali is dissolved and carried in the drainage water to the lower lying soils of the valley, in turn rendering them unfit for cultivation. Most of the alkali areas in the soils of the lower parts of the valley have been formed in this way.

The alkali found in the basins or lake bottoms came from the hills surrounding them. It has been washed into them by seepage waters until the amount they contain is very large. Springs are also the source of alkali, this being especially true of the soda lakes. The amount of alkali furnished by the springs, however, is slight compared with that which originates from the soils and certain of the rock formations. On account of the great store of alkali contained in the clays, shales, and sandstones much care should be exercised in irrigation and more attention paid to drainage to remove the salts as fast as they accumulate in the soils.

The character of the alkali found in the soils is much the same over the entire area. From a number of field determinations bicarbonates and sulphates were found to be the principal salts. Only very slight traces of carbonates were found. Chlorides occur in varying amounts, but generally in small quantities.

In the following table are shown the results of chemical analysis of an alkali crust from lake bottom:

Constituents.	Per cent.	Constituents.	Per cent.
Ions:		Conventional combinations:	
Calcium (Ca)	1.05	Calcium sulphate ($CaSO_4$)	3.56
Magnesium (Mg)	.88	Magnesium sulphate ($MgSO_4$)	4.37
Sodium (Na)	29.84	Sodium sulphate (Na_2SO_4)	88.95
Potassium (K)	.27	Potassium chloride (KCl)	.52
Sulphuric acid (SO_4)	66.14	Sodium bicarbonate ($NaHCO_3$)	.09
Chlorine (Cl)	1.76	Sodium chloride (NaCl)	2.51
Bicarbonic acid (HCO_3)	.06		
		Per cent soluble	91.46

On lands containing from 0.20 to 0.40 per cent of soluble salts in the first 6 feet of soil mature plants grow without injury, but it is difficult to get the less resistant plants started. Alfalfa can be grown on such soils, but when the upper limit (0.40 per cent) is reached the effect of the alkali is noticed in diminished yields. Sugar beets and barley, being to some degree resistant, will do well on such soils, but beans will not thrive, as the young seedlings are too tender. On soils which contain from 0.40 to 0.60 per cent of alkali only the most resistant plants will grow. If alfalfa is once established, it will continue to grow, but the yield will be light. Sugar beets and barley will do fairly well. Such soils are especially adapted to salt grasses, greasewood, and various alkali plants.

On soils containing from 0.60 to 1 per cent of alkali, the limit is about reached for cultivated crops. Where the soluble salt content of the soil is as high as from 1 to 3 per cent, it is practically impossible to grow any of the cultivated crops, and many of the salt grasses will not grow. Few weeds do well on such soils, greasewood and saltbushes comprising the principal vegetation. Lands containing over 3 per cent of alkali are practically bare of vegetation.

In the areas of gypsum the quantity of alkali varied from 0.20 to 3 per cent. The soil covering the gypsum is a loam, and the greatest amount of soluble salts occurred in the first 2 feet. The heavy clay soils contained on the average more alkali than any of the other soils of the area.

Much of the damage from alkali in the Laramie area must be ascribed to the excessive use of irrigation water. Fields that at one time were very productive have become practically worthless from the rise of alkali salts, and the water table has been raised to within a few feet of the surface in many places. Besides the rise of alkali, due to over-irrigation, considerable damage results from seepage from the canals. If catch canals were constructed along the main canal, where seepage is the worst, and if good drains were put in to carry away the surplus water used in irrigation, the rise of alkali in the soils would be checked, and in time the land could be reclaimed. The fall toward the river in most cases is ample, and on account of the loose texture of most of the soils drains would not have to be placed close together. In the lower lying areas, especially the old lake bottoms and basins, where there is no outlet, the problem of reclamation is more difficult. These places will probably remain alkali lakes, with the alkali continually increasing. Fortunately, however, these basins are only local, and are of relatively little importance.

SAN LUIS VALLEY AREA, COLORADO.

A soil survey of a part of the San Luis Valley in the southern part of Colorado was made by J. Garnett Holmes in 1903. This valley is situated in the south-central part of the State, and that section of the valley investigated has an average elevation of about 8,000 feet. As the rainfall is insufficient to produce paying crops, irrigation is practiced wherever crops are grown. Nearly the whole valley has artesian water at comparatively shallow depths, but this supply is used principally for watering stock. Water for irrigation comes mainly from the Rio Grande or the many small streams that issue from the mountains. The elevation and consequent short season limit the range of crops that may be grown, the principal ones being grain, peas, potatoes, and native grasses for pasture and hay.

The soils are nearly all very sandy, and generally have a high percentage of gravel, all being very leachy.

For all crops except the grasses for hay and pasture and limited areas of alfalfa, moisture is supplied by subirrigation. Water is run constantly during the growing season in small ditches from 150 to 300 feet apart in the fields, and the whole field subirrigated. This method is very wasteful of water, and has resulted in large districts becoming impregnated with alkali.

The reclamation of these alkali lands and the prevention of the spread of the evil has been discussed in the report upon this area, as follows:

> While not all of the alkali land of the valley will need to be drained, yet all the lands that need drainage, except those immediately along the streams, are alkaline, and some drainage is necessary in any comprehensive scheme of reclamation. Since, as has been several times stated, the accumulation of alkali is caused by the water coming from below or from subirrigation, the obvious thing to do to benefit the lands is to reverse the process and apply the water at the surface and let the current be downward. In order to make this possible, drains will have to be constructed on the wettest lands, and all the affected lands will need to be prepared so that in times of abundant water supply they will be liberally flooded.
>
> The soils of the valley are sandy, and their capillary power is very slight, so that with care in cultivation a very high water table may exist and yet but slight damage result from the rise of alkali. The principal crops of the country are shallow-rooted annuals, which are not injured by water comparatively close to the surface.
>
> In view of the fact that the alkali is wholly a surface accumulation, that the soil is sandy, coarse, open, and porous, and of very low capillary power, and that the crops are such as do not suffer from a high water table, it may be readily seen that any system of drainage either for alkali reclamation or for purely drainage purposes may be confined to a very limited part of the surface soil.
>
> The first step in this reclamation is to abandon the old method of exclusive subirrigation and prepare all affected lands for flooding. This will necessitate an initial expenditure of some money and labor, as small ridges and mounds must be leveled. Two dollars an acre, on an average, should be sufficient to cover this. Then, through the worst areas of alkali, and in the lowest parts, small drains should be constructed 2 or 2½ feet deep with an outlet into a main drainage ditch. This ditching should be done only after careful surveys and tests for alkali have been made, so that no unnecessary work be done and that the water table be not lowered sufficiently to make the lands too dry. Two dollars an acre, on an average, ought to pay for this ditching, which, together with the expense of leveling, would make a total outlay of $4 an acre for the affected lands. As soon as the lands are leveled and ditched, they should be heavily flooded to wash the alkali down, the salty water being carried away by the ditches. If one heavy flooding can be done in the spring before crops are sown, and then the crops flooded from time to time throughout the growing season, a crop can be grown the first year on almost any of the land that once grew crops. On the heavier soils, locally known as adobe, but represented on the map as San Luis sandy loam, the ditches would have to be closer together and deeper than on the sandy soils. This loam soil is usually much more alkaline than the sandy soils. On this heavier soil reclamation will be slower and more expensive, but when once reclaimed the land will be of lasting productiveness and very valuable.
>
> In reclaiming alkali land much loss can be avoided by planting only such crops as will withstand the quantity of alkali in the soil at the time of seeding. Land that will produce a paying crop of barley may be so alkaline as to be worthless for wheat and peas. A safe plan is to try first to grow only the most alkali-resistant crop suited to the climate. In the San Luis Valley this crop is barley, which, with the flooding, ought to produce fair crops the first year on any of the lands mapped as having less than 0.60 per cent of alkali. If the flooding be heavy and the crop shows little damage from alkali, it could be safely followed by a crop of peas. The peas should be grown as soon as possible in the reclamation,

as they greatly enrich the land and benefit the crop to follow. After a crop of peas is once grown, the ditches may be banked up in dry seasons and crops grown by subirrigation, if care be taken to flood the land every few years or when there is an abundance of water in the river.

The records show that at least once in four or five years there is sufficient snowfall to make a great surplus of water in the river. When once the lands can be made to produce crops, a copious flooding in these times of high water should keep the lands sufficiently sweet to grow crops in the intervening years by means of subirrigation. Lands immediately surrounding the abandoned areas have grown good crops for a number of years wholly from seepage from the higher lands, but they are beginning to show alkali on the surface and should be flooded. These wet lands surrounding the alkali areas are at present considered the most valuable in the valley, because they are not directly dependent upon the seasonal precipitation for their supply of moisture. As soon as the alkali lands are reclaimed they will rank with these lands in value, for a drought need never be experienced. The higher country to the westward acts as a water-storage region for these very lands, regulating the supply and always furnishing sufficient water for subirrigation in dry seasons.

After the lands are sufficiently reclaimed to grow the crops suited to this region, the greatest care should be exercised to prevent evaporation from the surface of the soil. Careful cultivation to preserve a mulch at all times when not actually growing a crop will do much to lengthen the time between floodings.

'If the above recommendations are carried out, there can be no doubt that many lands now abandoned may be brought back into a high state of fertility.

Appended is a table of analyses of samples of alkali soils of the valley. The alkali is very spotted, some districts having quite a little of the carbonate. Rational methods of irrigation, however, should result in the reclamation of any of these lands, if undertaken and pursued with continuity of purpose.

Chemical analyses of salts in alkali soils.

Constituent.	No. 1.—1½ miles west of Montevista; crust, 0 to ½ inch.	No. 2.—Center east side sec. 18, T. 39 N., R. 8 E.; crust, 0 to ½ inch.	No. 3.—East side SE. ¼, sec. 29, T. 40 N., R. 8 E.; crust, 0 to ½ inch.	No. 4.—No. 4-40, sec. 6, T. 39 N., R. 7 E.; crust, 0 to ½ inch.	No. 5.—NE. ¼ sec. 24, T. 41 N., R. 7 E.; crust, 0 to 1 inch.	No. 6.—NE. ¼ sec. 29, T. 41 N., R. 8 E.; crust, 0 to 1 inch.	No. 7.—No. 13-40, sec. 33, T. 41 N., R. 8 E.; crust, 0 to 1 inch.	No. 8.—7 miles southwest of Alamosa; crust, 0 to ½ inch.	No. 9.—½ mile south of Alamosa; crust, 0 to ½ inch.
Ions:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Calcium (Ca)	2.48	6.98	6.32	8.94	5.80	6.87	8.52	1.43	0.83
Magnesium (Mg)	.14	.96	.75	2.43	1.27	1.10	1.02	.08	.15
Sodium (Na)	28.49	22.90	21.92	11.00	23.05	23.82	17.61	30.06	33.05
Potassium (K)	1.59	.24	5.38	9.75	3.39	.18	7.27	1.07	2.06
Sulphuric acid (SO_4)	63.76	67.11	47.99	55.68	40.60	46.79	44.33	66.30	37.27
Chlorine (Cl)	2.33	....	15.39	....	17.40	12.91	16.03	.97	2.08
Carbonic acid (CO_3)	....	....	....	....	....	....	....	....	17.38
Bicarbonic acid (HCO_3)	1.21	1.81	2.25	12.20	8.49	8.33	5.22	.09	7.18
Conventional combinations:									
Calcium sulphate ($CaSO_4$)	8.42	23.73	21.46	30.28	19.66	23.35	28.97	4.86	2.96
Magnesium sulphate ($MgSO_4$)	.71	4.70	3.69	11.99	6.22	5.40	5.00	.40	.77
Potassium chloride (KCl)	3.04	....	10.26	....	6.50	.36	14.09	2.04	3.54
Sodium chloride (NaCl)	1.46	....	17.23	....	23.48	20.98	15.57	....	.99
Sodium bicarbonate ($NaHCO_3$)	1.65	2.53	3.06	17.07	11.88	11.45	7.15	.13	9.90
Sodium carbonate (Na_2CO_3)	....	....	....	....	....	....	....	....	30.73
Sodium sulphate (Na_2SO_4)	84.72	68.44	44.30	18.91	32.26	38.46	29.22	92.57	51.18
Potassium sulphate (K_2SO_4)	....	.60	....	21.75	....	....	....	....	....
Per cent soluble	15.07	1.66	3.20	.98	1.21	2.18	1.76	31.72	10.10

PROVO AREA, UTAH.

The Provo area was surveyed in 1903 by A. M. Sanchez. It includes an area of 370 square miles, and constitutes nearly all of the cultivated land of Utah County. The climate of the valley is characterized by a low annual precipitation, the total amounting to about 15 inches.

The area comprises two distinct topographic divisions. The first is an area of sloping land adjacent to the base of the mountains, and usually above the present systems of irrigation. This consists chiefly of coarse material, sand, gravel, stones, and bowlders, derived principally from wash from the mountains. The surface is usually rough and uneven. On account of insufficient water supply, a large part is not under cultivation. The second topographic region is larger and more level and is generally cultivated. It is composed of the finer sediments of ancient Lake Bonneville, subsequently modified by inflowing streams and weathering. The soils consist of clays, loams, and sandy and gravelly loams, with loams and gravelly loams as the prevailing types. The principal streams used for irrigation in the valley originate in the Wasatch Mountains. The water is of good quality, though generally the amount is insufficient for irrigating all the cultivated lands.

The level at which standing water is found is very changeable, depending on the character of the season. The principal cause of the high water table in much of the lands is seepage from irrigation on the higher lands. The wet lands to the east and southeast of Provo City and to the north of Spanish Fork, as well as in many other places, have been caused by seepage from the irrigation canals in the coarse and porous soils of the bench lands. It is obvious that great care should be exercised in the construction and use of canals, especially those on porous soils, and the unavoidable waste from the canals should not be allowed to accumulate in low places. Much of the wet land also is caused by springs and flowing wells, which are more or less numerous throughout the bottom lands. These wells keep the land in the vicinity saturated with water, making it swampy and unfit for cultivation, and while the water is usually free from injurious amounts of soluble salts, yet by continuous evaporation considerable alkali accumulates on the surface of the soil in these localities. A few ditches to conduct the water away from these wells to other parts of the fields, instead of allowing it to soak into the adjacent land, would prove very beneficial to lands already affected, and would prevent the further spread of alkali. There are at present over 2,000 acres of this wet land in the vicinity of Utah Lake, used chiefly for pasture and practically worthless, which, if properly drained, would have a greatly enhanced value.

On a small scale a certain amount of drainage is being done around Provo City, and in all of these cases fair success has been attained.

As a general rule, the alkali areas were found in lands of the lower levels, though in a few cases slight accumulations of salts were found in some of the bench lands. In the bottom lands the soil is usually heavier and poorly drained, and these conditions, together with the low position of the lands, favor the accumulation of soluble salts in the soil. For 2 or 3 miles from Utah Lake, and all along the side, more or less alkali land was found.

The principal source of the alkali in most of the area is in the evaporation of Utah Lake and seepage waters. While it is quite possible that some of the salts may be the result of the evaporation of the waters of former Lake Bonneville, which once covered this country, it is not probable that much of the salts found in the soil is directly derived from that source. Over most of the alkali areas found in the valley the surface of the soil is within capillary reach of the ground water, and consequently rapid evaporation at the surface is continually going on, with the result that salts are concentrated at this point. As a general rule, the greater part of the alkali found in the soils of this valley is in the first 3 feet of soil, little or no alkali being found below this depth. In some places of heavy soils underlain by clay the alkali is quite uniformly distributed throughout the first 6 feet of soil.

It was repeatedly noticed that the amount of alkali that sugar beets will stand is in great measure dependent on the character of the soil. In all cases it was found that where the soil was a loam or of heavier texture than a loam the amount of alkali required to injure crops was higher than where the soil was lighter in texture. Several cases were observed where sugar beets in a sandy soil were suffering with 0.65 per cent of alkali in the first foot of soil and 0.62 per cent and 0.55 per cent in the second and third foot, respectively, with the quantity of salt diminishing greatly in the lower depths. On the other hand, beets were found growing apparently well in a heavy loam soil with 1.40 per cent of alkali in the first foot, 1.50 per cent in the second, 1.55 per cent in the third, and an average of 1.50 per cent for the 6 feet. Similar observations on sorghum and alfalfa appear to confirm the above conclusions.

The following analyses of crusts give the chemical composition of the alkali in this area:

Chemical analyses of salts in alkali crusts.

Constituent.	NE. cor. sec. 19, T. 9 S., R. 1 E.	NE. cor. sec. 28, T. 9 S., R. 1 W.	SW. 4-40, sec. 10, T. 7 S., R. 2 E.	NE. cor. 6-40, sec. 3, T. 7 S., R. 2 E.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	2.96	0.34	1.48	0.52
Magnesium (Mg)	.97	.30	2.70	.72
Sodium (Na)	32.44	36.26	24.98	33.52
Potassium (K)	2.71	1.25	3.16	2.52
Sulphuric acid (SO_4)	1.18	3.55	45.91	12.22
Chlorine (Cl)	59.25	21.70	6.51	9.23
Bicarbonic acid (HCO_3)	.44	15.16	10.98	16.68
Carbonic acid (CO_3)	.05	21.44	4.28	24.59
Conventional combinations:				
Calcium sulphate ($CaSO_4$)	1.67	1.17	5.02	1.77
Calcium chloride ($CaCl_2$)	6.82	1.52	13.31	3.57
Potassium chloride (KCl)	5.14	2.37	6.05	4.82
Magnesium chloride ($MgCl_2$)	3.81	2.23	46.95	11.99
Sodium chloride (NaCl)	81.85	33.97	5.95	11.43
Sodium bicarbonate ($NaHCO_3$)	.61	20.88	15.18	22.95
Sodium carbonate (Na_2CO_3)	.10	37.86	7.54	43.47

In the Goshen Valley, with the exception of the bench lands immediately adjoining the mountains, and a few other small areas in the bottoms, sufficient salts occurred in all the soils materially to injure the crops or entirely to prevent profitable cultivation. Many large areas were found containing from 1 to 3 per cent of alkali. In this class of soils it is doubtful if any of the common agricultural crops will grow with any degree of success.

Black alkali (sodium carbonate) was found in more or less injurious quantities in some parts of the valley. It was seldom found, however, in amounts exceeding 0.10 per cent outside the Goshen Valley without the presence also of an excess of white alkali. In the Goshen Valley much of the land contained from 0.10 to 0.30 per cent of sodium carbonate. None of this land was then under cultivation, and it was evident from surface conditions that no agricultural crops would grow in the soil.

There is no doubt that the alkali soils of this valley, most of which are at present practically worthless, would, if freed from alkali and supplied with sufficient moisture, grow successfully any crop adapted to the region. There were at the time of the survey 49,408 acres of land in the valley containing more than 0.40 per cent of alkali to an average of 6 feet. Over most of this land soluble salts occurred in sufficient quantities either to be injurious to crops or entirely to prevent successful cultivation. The value of most of this land was nominal, varying from $5 to $15 an acre. If properly reclaimed, it would be worth, under irrigation, at least $80 an acre.

The following table shows the extent of the several grades of alkali land in the area:

Areas of alkali lands.

Grade.	Acres.	Per cent.
Less than 0.20 per cent	159,488	69.9
From 0.20 to 0.40 per cent	29,824	11.6
From 0.40 to 0.60 per cent	15,680	5.7
From 0.60 to 1 per cent	10,368	3.9
From 1 to 3 per cent	23,360	8.9
Total	238,720	....

BAKER CITY AREA, OREGON.

The Baker City area was surveyed in 1903 by Charles A. Jensen and W. W. Mackie. The area includes about 158 square miles situated in Baker County, in northeastern Oregon. The climate of the area is practically arid, as the rainfall is not properly distributed during the year to grow crops without irrigation. The annual rainfall at Baker City is about 14 inches. Baker Valley is about 3,300 feet above sea level, and is completely surrounded by mountains ranging from 1,000 to 6,000 feet above the valley level.

The soils consist of loams and gravelly and sandy loams. The soils are not deep, and everywhere in the valley proper they are underlain by coarse, well-rounded gravel. There is evidence that the soils in the central part of the valley have been brought there from the mountains by the streams and supplemented by washings from the foothills, while the soils along and just below the foothills are colluvial in origin.

The chief constituent of the alkali in the cultivated valley soils was found to be alkaline carbonate or black alkali. The subsoil water carries bicarbonates in solution, and when this water reaches the surface by capillarity it evaporates and leaves the salts behind. As evaporation proceeds the hydrogen carbonates, or bicarbonates, lose water and carbon dioxide, which changes the salts to the normal carbonate or black alkali. The subsoil also contains some alkaline carbonates, and the capillary attraction of these salts being much greater than that of any other constituent in the soil there is a strong tendency for these to concentrate at the surface. The surface deposit of alkaline carbonates is thus due partly to its formation from the hydrogen carbonates and partly to the salts being brought up directly from the subsoil.

In the southeastern part of the area, in one of the sandy loam types, the subsoil contained considerable alkali. The maximum salt content occurred in the third and fourth foot sections, and but very little, or less than 0.20 per cent, in the surface foot. The alkali here owed its origin to the decomposition of the rocks from which the soil has been derived, and was principally white alkali, although considerable alkaline carbonate was also found. These latter salts have also been formed in place. There is a great deal of lime in the subsoil of this type, and the calcium and magnesium carbonates have been dissolved to a certain extent, resulting in the formation of the hydrogen carbonates of their bases. These hydrogen carbonates then react with the soluble sodium and potassium salts, such as chlorides and sulphates, which are present in considerable quantities, forming the hydrogen carbonates of sodium and potassium. These upon reaching the surface change to the normal carbonates by the loss of carbon dioxide and water. Some alkaline carbonates are also formed in the subsoil, as these were found from 4 to 6 feet below the surface. The calcium and magnesium carbonates are soluble as such to some extent especially in the presence of other salts in solution. These carbonates then react directly with the sodium and potassium salts, forming soluble alkaline carbonates. But here, again, the strong capillary attraction of these salts causes them to be concentrated at or near the surface. In some cases as much black alkali was found in the second foot as in the surface foot.

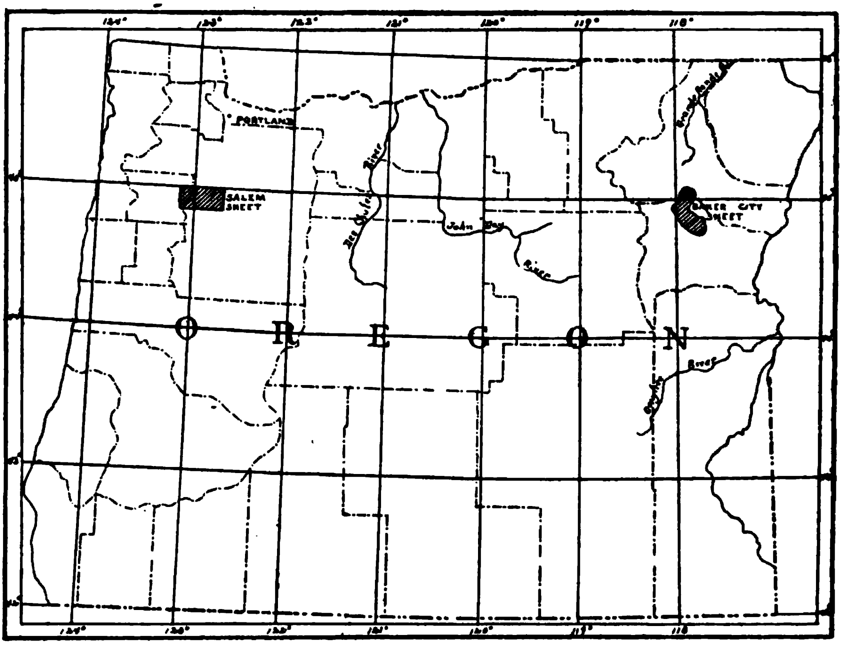

FIG. 11.—Sketch map showing location of areas in which alkali has been studied in Oregon.

In the areas of bad alkali surface conditions the alkaline carbonates were always present in excess of any other single component of the soluble salts, with the exception of hydrogen carbonates, and these are in reality potential alkaline carbonates. Sulphates were very often found, sometimes in large quantities, in the presence of the alkaline carbonates. Chlorides were nearly always present, but always in smaller quantities than the alkaline carbonates. The amount of hydrogen carbonates seldom exceeded that of the alkaline carbonates by more than two or three times.

Owing to the fact that in cultivated areas the maximum salt content occurs usually in the surface foot, the problem of alkali reclamation is not so serious as it would be if the subsoil contained excessive amounts of alkali. The character of the prevailing alkali—alkaline carbonates or black alkali—makes it necessary to prevent the surface accumulation of alkali as far as possible. The black alkali in the cultivated areas owes its origin to the evaporation of the subsoil water at the surface. Were the water table kept far enough below the surface to check this capillary process, it is evident that there would not be so much black alkali on the surface. The subsoil water should not be permitted to come nearer the surface than 6 feet. This can be accomplished by an economical use of water on the soils in which the underground water table is not yet too near the surface, and by underground drainage where the water table is already too high.

An attempt was made to obtain some information as to the resistance of different crops to alkaline carbonates. This is a difficult problem, because the conditions in the field are continually changing. The alkaline carbonates being readily soluble, every rain and every irrigation changes the concentration of the salts in the surface foot of soil. Again, when a long dry period occurs, and the temperature is high, evaporation is greatly increased, more subsoil water is brought to the surface, and the amount of the carbonates is considerably increased.

The following table exhibits the results obtained where the conditions appeared to have been comparatively constant, both in regard to crops and alkali content. The borings were made at the root crowns of the plants.

Tests for resistance of crops to alkaline carbonates.

Boring No.	Crop.	Condition of crop.	Alkaline carbonates.	Chlorides.	Sulphates.
			Per cent.	*Per cent.*	
54	Oats	Poor; hardly worth cutting	0.065	None.	None.
78	do	Good	.03	0.055	Trace.
96	do	Dead	.05	.04	None.
97	do	Dying after growing about 8 inches.	.04	.07	Heavy precipitate.
97	None	(Second foot of soil)	.03	None.	Light precipitate.
102	Oats	Growing fairly well, but in chlorose condition.	.03	None.	None.
105	do	Same condition as No. 102	.05	None.	Do.
186	do	12 inches high, but not good crop	.05	.225	
185	do	2 to 3 feet high, well headed out	.08	None.	Do.
138	Wheat	Fairly good; will make average crop.	.035	None.	Do.
141	do	Entirely bare ground; surrounding wheat 3 feet high.	.065	.16	Moderate precipitate.
142	do	Good; 2 feet high and fully headed out.	.04	Trace.	None.
153	do	Fair; plant 18 inches high, but not profitable crop.	.05	.16	Heavy trace.
136	Timothy	Good; but only average crop; not heavy.	.07	None.	Not tested.
166	Barley	Matured, but plants stunted, and poor stand.	.05	.025	Moderate precipitate.
182	Alfalfa	Chlorose, but growing fairly well; second crop.	.08	None.	None.
183	do	Good; fair stand; second crop, 8 to 10 inches.	.08	None.	Do.
184	do	Good; best that could be found in field.	.03	None.	Do.

It will be noticed that the presence of sulphates has considerable influence on the plants, since they apparently would not stand so much of the alkaline carbonates when the sulphates were absent. It is probable that some of the sulphate was magnesium, a salt which has as deleterious an effect on plants as the alkaline carbonates. It is very likely that in these tests the effect of the alkaline carbonates was modified by the presence of magnesium sulphates. The chlorides would undoubtedly have a somewhat similar effect, though to a less extent.

SAN JOSE AREA, CALIFORNIA.

The San Jose area was surveyed in 1903 by Macy H. Lapham. It occupies the northern part of the depression extending in a southeasterly direction from the southernmost extremity of San Francisco Bay and known as the Santa Clara Valley. This valley is one of the largest of the several coast valleys, and is of great economic importance to the State. The average annual rainfall in the valley is about 15 inches. Fogs are of frequent occurrence, usually appearing during the night and early morning of the summer months.

The soils are mainly of alluvial or colluvial origin, and are derived, by weathering and waste, from a complex variety of rocks of the surrounding mountains. In texture they grade from incoherent sands to extremely heavy and sticky adobes, usually occupying valley depressions, but sometimes extending over foothill slopes. With the exception of the axial valley trough and a few local depressions, these areas are well drained, and the accumulation of alkali salts has not taken place to so serious and extensive a degree as in the great interior valley.

Irrigation is usually practiced in the fruit districts, the supply being drawn mainly from an underground source by pumping. None of the waters used for irrigation purposes, whether drawn from wells or from streams, were found to contain injurious quantities of alkali. Of the underground supply, that drawn from the deeper wells is usually most pure. Owing to the cost of pumping and to a limited supply of irrigating waters which may be obtained from streams, there is a very general and commendable economy in the use of water for irrigation purposes, which is generally carried through iron pipes to the point of delivery, thereby entirely preventing loss by seepage. The advantages of frequent cultivation in preventing loss of soil moisture by evaporation are also generally recognized.

Alkali soils are not of general occurrence throughout this survey. They occur, however, in a few valley depressions and districts of arrested drainage, covering quite an extensive tract of heavy silty loams and adobe occupying a pronounced depression a short distance east of the city of San Jose, and extending in a northwesterly direction to the salt marshes of San Francisco Bay. Some of these soils are in this vicinity quite heavily impregnated with alkali salts, which an examination of waters from shallow wells indicates extend to considerable depths. In these salts the more destructive black alkali is lacking. Considerable portions of these areas have been already drained by tile and occasional open ditches. Owing to the limited supply and the high cost, no large amount of water is available for purposes of reclamation. The chief cause of these alkali-impregnated soils seems to have been the concentration of the salts by seepage from irrigation carried on upon adjoining higher fruit lands of porous structure. The condition of much of this land can be improved by an extension of the drainage systems. In the vicinity of the tidal marshes encircling the southern extremity of San Francisco Bay the soils are heavily impregnated with marine salts from saturation by sea water. A system of levees, drainage by pumping, and shallow cultivation might render a larger portion of this land available for grazing purposes, and in time perhaps capable of producing certain crops.

IMPERIAL AREA, CALIFORNIA.

In the winter of 1901 a soil survey was made of a part of the Salton Basin. Later, in the fall and winter of 1902–3, the survey was extended to include all of the region known as the Imperial country.

The whole Imperial country is a part of the Salton Basin, a former arm of the Gulf of California, which was cut off by the deposition of sediment from the Colorado River. Subsequent evaporation left dry the basin that is now being farmed. Rainfall is of such infrequent occurrence that no useful crops can be grown without irrigation, making a desert in the true sense of the word. The summers are intensely hot, the temperature often reaching 120° F. in the shade. The winter climate is not unpleasant, being characterized, however, by a great daily range in temperature. At night the thermometer often reaches 20° F., while the maximum is rarely less than 70° F.

All the soils of that part of the basin known as the Imperial country are made up of sediments brought in by the Colorado River. While some sand and sandy loam soils are found, the greater portion is made up of a heavy, sticky, compact loam and clay. These heavy soils are so compact that water penetrates them very slowly, and hence they are exceedingly difficult to cultivate or irrigate. Moreover, the whole valley, either in the surface or the subsoil, contains much alkali. That is, all the subsoil and much of the surface soil have alkali in harmful accumulations.

Generally considered, the drainage of this region within the soil itself is very poor. The channels of New and Salton rivers, and many deep gullies leading into them, furnish excellent regional drainage, with the lower part of Salton Basin as an emptying place.

At the time of the surveys the water table was from 20 to 40 feet below the surface and had in no wise been altered by irrigation.

Much of the land in the virgin state had such a percentage of alkali at the surface as to require sweetening by heavy flooding before profitable crops could be grown. Usually the amount of alkali increased with depth, if the surface had less than 1 per cent. The problems, then, that confronted the irrigators of the Imperial country, which are practically the same to-day, were: First, actually to reclaim from alkali much of the lands of the valley before any crops could be grown; second, to prevent the rise of alkali from the subsoil in a region where the subsoil is universally impregnated with salt and with a table of salty water 20 to 40 feet below the surface.

This matter is discussed at length in the report made upon the region in 1903, the following being a quotation from the same:

> In many regions, where lands originally good have become alkaline, the injury has resulted from the ignorance or carelessness of the agriculturists. A thorough knowledge of soil conditions at the beginning of cultivation, a carrful, rational application of water in irrigation, and a system of cultivation and rotation of crops tending to benefit the land permanently would have been possible in most of these cases, and the harmful accumulations could have been wholly or partially prevented. But the danger has not been seen, or at least not admitted, until a part of the land has been so badly affected as to produce no crops. It is always easier to prevent the injury of lands than it is to reclaim them after they have become alkaline, and as long as partial crops can be grown, some returns can be had from the land itself for the money expended.
>
> The people of the Imperial country should recognize the fact that aside from the general problem of securing water for irrigation they have to solve perhaps the most serious agricultural problem of the arid West. Here is found a most refractory soil, much of it highly impregnated with alkali. The only way to benefit the land is to carry away the salts. The application of gypsum can not be of the slightest benefit. Little or no benefit will be derived from running water across the land with the expectation of flushing the alkali off the surface. The first water run onto the land may dissolve the surface salt and sink it into the soil a little way, but repeated tests made in this way have shown that the water as it comes off the lower end of the field contains no appreciably greater proportion of salt than when it was taken from the ditch above. The water must pass through the soil and find ready egress through natural or artificial drainage ways.
>
> The quantity of salt taken out of the soil by alkali-resistant crops, such as sorghum and sugar beets, is not appreciable, the benefit to the soil in such cases resulting mainly from the prevention of evaporation at the surface through cultivation and from the leaching of the salts into the subsoil by the irrigation water. If the subsoil be practically free from salt, as is often the case in arid regions, this vertical distribution of the salts alone is often all that is necessary so to reclaim the soil that sensitive crops can be grown. But it has been shown that in the Colorado desert the subsoil is the greatest source of danger, so that every bit of salt removed should be permanently removed. Whether this can be done depends wholly upon the drainage. The rapidity with which water leaches through and drains away from a soil is dependent upon the texture of the soil and subsoil. A loose, friable, sandy loam or sand takes and gives up water very readily, so that such a soil should be easily washed free from salts if there be an outlet for the drainage water. On the other hand, a sticky clay or loam takes water slowly, and drainage in such soils is poor. By far the greater extent of the soil of the valley is a sticky, plastic loam or clay, through which water passes very slowly. The natural drainage in the soil itself is very poor, and to be anything like adequate it must be supplemented by artificial drains to carry off the ground water as the salts are washed down from the surface. The channels of New and Salton

rivers furnish good natural outlets for these drains. If the heavier soils be drained and care be exercised in the handling of the lighter ones, little damage will be done to the latter. Tile drains are the best and in the end the most economical for draining the land. They are, however, expensive, and the question is, Will it pay?

Thoroughly to tile-drain the heavier soils will cost at least $25 an acre, and the work can be properly done only in a large way and through the cooperation of all the farmers in maintaining the main drains, etc. For the very worst alkali lands this will have to be done before any paying crops can be grown at all, and it is only a matter of time until it will have to be done on some of the other soils that will now produce fair crops. This cost, added to the cost for water stock, makes an initial expenditure of about $40 an acre.

That it will eventually pay to drain these lands there can be little doubt, but in the present state of the country concerted action will be difficult and individual effort futile.

Many of the present landowners have expended all their capital for first payment of water stock and for farm equipment, expecting to obtain sufficient revenue from crops to meet future payments and to improve their farms, and for these the expenditure of the sum necessary to reclaim the badly alkaline lands is out of the question. They can not wait for the lands to be reclaimed, and unless their first crops are a success they will be unable to meet their payments. Thus a scheme of reclamation that would be not only possible but profitable for a wealthy company or corporation is, under present conditions, well-nigh impossible for the individual landowner of the Imperial area.

The conditions can, however, be at least temporarily improved and the rise of alkali delayed by individual effort. The aim should be to loosen the heavier soils in every way possible, to assist the natural drainage, and to see that in irrigation all parts of the field are covered. Irrigation by surface flooding should be the only method of applying water on soils carrying at present a harmful quantity of salts, and for the lighter and freer soils a system of irrigation should be followed that will permit occasional flooding to wash below the surface accumulations that will be inevitable with furrow irrigation.

Moreover, on such soils as those of the Imperial area, in all cases where the harmful amounts of alkali lie in the subsoil and not in the surface, it should be possible so to irrigate using only enough water to grow grains or other shallow-rooted annual crops, that connection between the subsurface and the irrigation water will not be made, thus preventing the rise of alkali. Such careful irrigation can be continued indefinitely without injury to the land When the surface 2 feet or so of soil contain an excess of salt, however, or when the salts from below have risen through the improper application of water or the rise of the water table, then it is useless to attempt cultivation with the sparing use of water, but the opposite method of thoroughly drenching the land, which has first been provided with adequate subdrainage, is the only safe and efficient one to follow. The one idea in this method is actually to wash and sweeten the land, dissolving the salts in the irrigation water, and carrying them away in the water passing off through the drains. The quantity of salts that can be removed in this way when the soil allows a ready percolation of water, the flooding is heavy, and the drainage system adequate, is astonishing. Means, in Bulletin 21 of this Bureau, points out that in Egypt lands of the heaviest character, containing 8 or 9 per cent of salt to a depth of several feet, with surface accumulations often as high as 40 or 50 per cent salt, are commonly reclaimed sufficiently to grow resistant crops in one year, cotton in two or three years, or corn in four years. In order to accomplish this, the drainage water must remove hundreds of tons of salt for every acre reclaimed.

Of the 693,696 acres surveyed, 296,256 acres of the level part contain less than 0.40 per cent of alkali. All of this part may be cultivated indefinitely to all the crops suited to the soil and climate, provided care is taken in irrigation and cultivation to prevent a rise of the salts from below. Of the remainder, 91,008 acres contain from 0.40 to 0.60 per cent. This amount, while dangerous, may, if carefully flooded, admit of several crops being grown before the ground water is raised sufficiently to injure the land permanently. This acreage of less than 0.60 per cent is alone enough to make of the area quite a wealthy agricultural district, alkali-resistant crops being grown on the worst lands, and other crops suited to the climate on those less alkaline and sandy enough to allow intertillage and the deep penetration of the roots.

It is highly probable, however, that the next few years will see an entirely new system of agriculture for these lands. Date palms for the delta have long been talked of, and the Department of Agriculture is experimenting with these in the Southwest, with every indication of success. There is hardly any land on the desert that will not grow these if the climate is suitable, so that this crop may be the ultimate solution of the alkali problem for much of the desert.

The soil is wonderfully fertile, and, irrigated with the sediment-laden water of the Colorado, must remain so. The ultimate total reclamation and profitable cultivation of the desert will surely take place. The greatest question at present is one of expediency, namely, How can the reclamation take place and yet protect the present owners from loss? It is believed this can best be done by cultivating at present only the lands that will produce profitable yields of the crops now being grown and by leaving the badly alkaline lands to be reclaimed when a new system of agriculture has raised the price of land to a point where it will justify the expenditure and when the need for reclamation has been recognized by everyone interested in the country, so as to secure a complete cooperation of all concerned.

In the summer of 1904 the Reclamation Service of the U. S. Geological Survey made a study of the crops of the region. This study showed 31,318 acres in crops. Of this amount 30,012 acres received sufficient irrigation, and 1,306 acres were insufficiently irrigated. Three hundred and thirty-seven acres of good crops were produced; 18,425 acres were fair; and 1,125 acres were poor crops. Not all of the failures were due to alkali, but a trip to the district in November, 1904, showed that the greater part was unquestionably due to the presence of excessive quantities of alkali.

The salts of the basin are all of the white alkali variety—principally chloride of sodium. Appended is a table showing a number of analyses of the alkali of crusts and soils from the basin:

Chemical analyses of alkali soils and subsoils.

Constituent.	8030.	8031.	8032.	8033.	8034.	8035.	8036.	8037.	8038.	8039.
	NE. cor. sec. 15, T. 16 S., R. 12 E.	NE. cor. sec. 11, T. 17 S., R. 13 E.	Subsoil of 8031.	E. side 3–40 sec. 33, T. 11 S., R. 14 E.	NE. cor. sec. 1, T. 15 S., R. 15 E.	Subsoil of 8034.	One-fourth mile W. of Volcano.	Subsoil of 8036.	NW. cor. sec. 18, T. 11 S., R. 14 E.	Subsoil of 8038.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	11.26	15.63	12.57	2.21	7.05	6.61	7.83	9.09	6.91	3.11
Magnesium (Mg)	3.15	2.91	1.92	1.10	2.86	3.23	2.30	3.66	2.02	2.74
Sodium (Na)	11.71	11.88	17.18	27.15	26.08	23.82	24.82	20.21	24.77	26.58
Potassium (K)	4.96	2.29	3.27	1.93	.36	1.32	.87	1.00	1.70	1.59
Sulphuric acid (SO_4)	31.54	24.59	26.24	32.14	7.60	14.27	15.67	24.17	23.20	32.16
Chlorine (Cl)	15.77	32.70	36.72	15.52	55.27	45.46	47.39	39.92	39.79	29.84
Bicarbonic acid (HCO_3)	21.61	10.00	2.10	19.95	.78	5.29	1.12	1.95	1.61	3.98
Conventional combinations:										
Calcium sulphate ($CaSO_4$)	38.32	34.78	37.17	7.48	10.75	20.15	22.21	30.91	23.47	10.54
Calcium chloride ($CaCl_2$)	.....	15.00	4.50	.....	10.80	1.91	3.62	.....	.....	.....
Magnesium sulphate ($MgSO_4$)	5.85	.....	.....	5.26	.....	.....	.....	2.95	8.30	13.64
Magnesium chloride ($MgCl_2$)	7.20	11.47	7.54	.....	11.21	12.65	9.04	11.99	1.39	.....
Sodium sulphate (Na_2SO_4)	.....	.....	.....	33.51	.....	.....	.....	.....	.....	20.46
Sodium chloride (NaCl)	9.45	20.39	41.68	22.72	65.48	55.59	61.95	49.60	61.41	46.86
Potassium chloride (KCl)	9.45	4.61	6.25	3.00	.70	2.50	1.65	1.89	3.23	3.01
Sodium bicarbonate ($NaHCO_3$)	29.73	13.75	2.86	27.43	1.06	7.20	1.53	2.66	2.20	5.49
Per cent soluble	.45	.96	3.42	.72	7.69	1.16	6.41	3.38	4.46	2.26

INDIO AREA, CALIFORNIA.

In 1903 a soil survey was made of the area about Indio, Cal., by J. Garnett Holmes. This area is situated at the upper end of Salton Sink and is separated from the Imperial country by the broad expanse of the low, moist, salt-bearing portion of the sink. The climate of the two areas is practically the same. There is a great difference, however, in the soil and alkali conditions.

This question is discussed in the report made upon this area, as follows:

> The gravity of the alkali problem in any arid country is dependent upon the amount and kind of salts in the soil, the amount of salt in the irrigation water, and the drainage of the country. Drainage may be taken to include not only the drainage of the country as a whole, in the sense of being free from excessive amounts of ground water, but drainage within the soil itself—the rate at which the water leaches through the soil.
>
> The alkali map which accompanies this report shows much of the valley to contain excessive amounts of alkali. To the uninformed observer this would seem to be a very grave state of affairs, for some of the percentages shown on the map are too great to permit the growing of many of the common crops. This alkali, however, is all at or near the surface of the soil. Here there are no deep-seated alkali deposits, the ground water all over the valley is of good quality, and no alkali is found below the ground water. Since the ground water is nearly always near the surface the soil lying above the water table (except in the lower levels) contains practically all the alkali in the vertical section of soil. About the Salton Sink the ground water has taken up enough salt from lateral percolation through alkali lands above to be quite salty.
>
> The ground water comes from heavy rainfall and melting snows in the mountains surrounding this part of the basin. The waters of old Whitewater River, which flowed into the bay when this was an arm of the sea, disappear in the sands near Indio and find their way to the sink through subterranean channels. Thus there is a continual stream of underground water passing through the soils of the valley. For this reason the valley may be said to have poor regional drainage, while the drainage of the soil itself, its permeability, is very good.
>
> The slope of the country mapped is on an average 12 feet to the mile, and for that part between Walters and Indio it is nearly 20 feet to the mile. With the coarse soils and heavy grades there would be no trouble about drainage if it were not for the steady stream of underground water flowing through the soil. This has been the source of all the alkali trouble. It has come so near the surface that in the trough of the valley evaporation from the surface has alkalied a considerable part of the lands. Since the drainage in the soil itself is good, the obvious thing to do is to devise some means of carrying off this ground water more quickly than is the case where it leaches through the soil. If the water table could be permanently lowered, the soil generally would not need to be drained artificially, and one or two heavy floodings would so reclaim the worst soils that alkali-resistant crops could be grown. All that is necessary is to lower the ground water and flood the surface, being careful to cultivate the soil as soon as possible after each wetting, so as to prevent the evaporation of water from the surface and the deposition there of the alkali carried in solution.
>
> The best method of draining the valley can be determined only after careful surveys, but in all likelihood a long, deep, open ditch running down the center of the valley, with lateral ditches on both sides, would be sufficient to keep the general level of the ground water below 6 feet.
>
> Whatever the method adopted for the general drainage and reclamation of the lands of the valley, the individual farmer will be dependent upon his own knowledge and resources for the reclamation of his own particular field. In this reclamation work he should keep

in mind the well-established principle that alkali follows the water until evaporation takes place. His energies should be devoted to the prevention of evaporation from the surface of his land, for it is at the surface that alkali does most damage to young and tender plants. The best method of getting alkali out of the land is by heavy surface flooding. Except where the water table comes to within 6 feet of the surface the land of the valley can be entirely reclaimed in this way. The alkali being washed into the subsoil and kept there by preventing surface evaporation will eventually be carried away by the stream of subterranean water.

Flooding without drainage, while it betters the lands lying at higher levels, can not fail to be detrimental to lands lying at a lower level. Since a comprehensive system of reclamation, to include the whole of the valley, is so simple and can be placed in operation so cheaply, it seems a very unbusinesslike procedure to injure one part of the valley in order to better another part when all might be permanently reclaimed.

The greatest obstacle to reclamation is the comparatively small head of water at the command of individual landowners. All the water is from artesian wells, and irrigating is done only on a small part of the farm at one time and usually by the furrow method. The capacity of the wells is not great enough to flood very much of the open, sandy soil. The porous nature of the soils makes it almost impossible to combine the flow of wells situated at some distance from one another. This state of affairs can no doubt be remedied by making larger wells, which will be capped and allowed to flow only when the water is needed for irrigation.

When the land is flooded the greatest care should be taken to have all the surface leveled. Any hummocks or ridges extending above the water will furnish points from which the water will evaporate, and the current, instead of being wholly downward, will be partly toward the surface, and much of the alkali washed from the soil in the immediate vicinity will be deposited on these high spots.

After the land has been partially reclaimed, furrow irrigation may be practiced, as this method is much more economical of water, and the crops adapted to this valley, such as melons, grapes, truck, etc., are more easily irrigated in this way. Where furrow irrigation is practiced, care should be taken to have the furrows as deep as practicable without injuring the plants and to cultivate the soil as soon as possible after irrigation. When ridged crops, such as sweet potatoes and melons, are grown, borders should be thrown up, dividing the field into lands, and these lands should be flooded after the crop has been harvested, the surface being cultivated immediately afterwards. This flooding may not be necessary every year, but in any other method of irrigation than flooding a periodical flooding is necessary in order to wash into the subsoil the small amount of surface accumulation of salts that are found in even the most carefully cultivated fields.

If ordinary care is exercised in the cultivation of the lands of this valley, there is no reason why they should not become steadily better, until even the most sensitive crops can be grown and trouble from alkali ceases entirely.

KEARNEY AREA, NEBRASKA.

The Kearney area was surveyed in 1904 by J. O. Martin and A. T. Sweet. It includes that part of the Platte Valley in south-central Nebraska lying between the ninety-ninth and one hundredth meridians of west longitude. The area contains about 792 square miles. The climate is typical of the great semiarid plain east of the Rocky Mountains, the annual rainfall being about 20 inches. The topographic features of the area consist of a broad, flat valley floor bordered on each side by a dissected upland plateau. The soils in the valley proper represent reworked materials laid down by the Platte River.

The soils of the uplands are weathered glacial débris, in many respects resembling loess. Water for irrigating purposes is taken from the Platte, but owing to the abundant rainfall for several years preceding 1904 there had been but little need of irrigation. The water table lies at distances from the surface varying from a few feet to about 40 feet. There are generally two veins of water, the upper one containing the higher percentage of soluble salts.

Beginning at Odessa and stretching westward there was found an area in which much of the soil contained enough alkali to be injurious to crops. For the most part the alkali spots lay to the north of the Platte River. These alkali areas grew larger and more numerous toward Lexington, beyond which they gradually diminished in size and number, so that the worst affected areas were found between Lexington and Overton. South of the Platte, near Lexington and Cozad, areas of alkali land were also found.

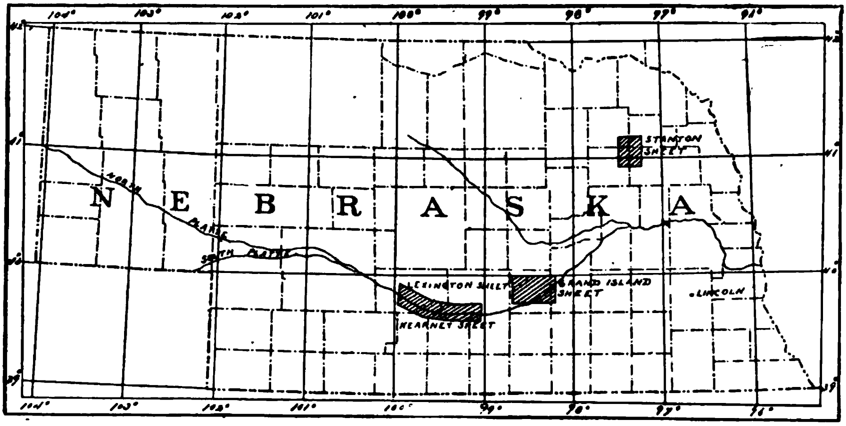

FIG. 12.—Sketch map showing location of areas in which alkali has been studied in Nebraska.

The origin of the alkali is not obvious, but it appears to be an accumulation through many years of wash from the upland valleys, traces of alkali in small quantities frequently showing on the sides of these valleys. Washed into the valley and remaining in its most poorly drained portions, these small quantities are concentrated by evaporation during the dry seasons. The ground water also becomes impregnated with alkali to a greater or less degree and, where it is near the surface, becomes a continuous source of supply.

The chemical composition of the alkali in these areas is quite variable. It consists mainly of salts of sodium, potassium, and calcium, with some magnesium in various combinations. From analyses it was found that sodium and potassium salts predominated. The distribution of the alkali in the soil was very irregular, as scarcely any two vertical sections gave the same results. At the time the examination was made the season had been unusually wet, and this may have had a great deal to do with the irregular distribution of the alkali in the soil.

All of the lower valley soils would be benefited by drainage, but the fall is so slight that the drainage of individual tracts would be difficult, and the result could best be accomplished by the construction of large public or corporate ditches into which individuals could discharge their drains.

GREELEY AREA, COLORADO.

In the summer of 1904 a soil survey was made by J. Garnett Holmes and N. P. Neill, of the Cache la Poudre Valley (Greeley area) in northern Colorado. This survey includes parts of Larimer and Weld counties.

The area surveyed lies at an elevation of between 4,000 and 5,000 feet. Rainfall is insufficient to grow a wide range of crops, but with careful cultivation should be sufficient for fair crops of grain or other drought-resisting cultures. The summers are cool and pleasant. Winter temperatures of 40° F. below zero are reported. The whole country is a rolling, undulating prairie, the only land that even approximates a level surface being the small valleys along streams and creeks. With the rainfall and the generally rolling surface no accumulations of alkali should have occurred if ordinary precautions to insure drainage for the level valley floors had been taken. Shortly after irrigation began, however, these lower valley areas were allowed to become swamped, and a consequent accumulation of alkali has occurred in many of these lands. Practically all the soils are leachy and porous, permitting much seepage from ditches and irrigated fields. This seepage water rapidly accumulates in the lower soils, greatly raising the entire water table of the region, but actually damaging none but these lowlands. Sufficient drainage to carry away the surplus water from these lowlands, with a few heavy floodings, should rapidly bring all the damaged lands again into a high state of fertility. This is being done in many instances, and already many acres have been reclaimed. The building of beet-sugar factories at several points in the valley has made the growing of sugar beets a very profitable business, and since the accumulation of alkali has rarely reached such a state that this crop will not grow if the surplus ground water is removed mere drainage is often sufficient to bring the lands into such a condition as to be immediately valuable.

The common practice in draining is to make a three-sided box or trough of pine boards, which is used as a drain, being placed at the greatest possible economical depth. The water developed from these drains is used at lower levels for irrigation. The alkali is all of the white variety, in which there is much gypsum. It is the common belief among those having experience that this gypsum would fill the pores and joints of drain tile and render them inoperative. Board drains as described above are cheap and efficient and if well installed give no trouble. All of the lands in the valley now considered too alkaline to grow crops can be thus cheaply and profitably reclaimed. The people are interested, and no doubt the work will receive great extension.

BEAR RIVER VALLEY, UTAH.

The Bear River area was surveyed in 1904 by Charles A. Jensen and A. T. Strahorn. Bear River Valley lies in north-central Utah. The area includes practically all the irrigable land in the valley within the State, and also part of the former bed of Great Salt Lake. The climate of the area is semiarid, having an annual rainfall of nearly 12 inches at Corinne. The surface features of the area fall into three divisions: The cultivated mountain slopes on the east and west sides of the valley; the low-lying flat bottom lands formerly covered by Great Salt Lake in its concentrated condition; and the higher lying and level prairie lands north of the lake-bottom lands and included between the mountains. The soils consist principally of former lacustrine deposits, including many loam and sandy loam soil types. Water of excellent quality for irrigating purposes is taken from Bear River.

The extent of the various areas of underground water during the progress of the survey, in 1904, is shown in the following table:

Areas of underground water.

Depth.	Acres.	Per cent.
Less than 3 feet deep	64,640	30.3
From 3 feet to 6 feet deep	57,216	26.7
From 6 feet to 10 feet deep	39,808	18 6
Over 10 feet deep	51,968	24.3
Total	213,632	....

The underground water is often very salty. This is especially true of the level area north and west of Corinne. The surface well waters examined contained from 150 to 500 parts of salts per 100,000 parts of water. These salts consisted principally of chlorides, with some bicarbonates and from 3 to 20 parts of alkaline carbonates, or black alkali. Sulphates were not often present. The deeper-seated waters are more salty, generally, than the surface well waters, especially west of Bear River. The underground water along the east side of the valley is very good, containing very little alkali. There are many salty springs in the area, especially at the south end and west side of Little Mountain. These contain from 2,000 to 3,000 parts of salts per 100,000 parts of water.

One of the best indicators of future alkali conditions is the position of the underground water table. As will be seen from the above table, this water is already dangerously near the surface, especially in the western part of the valley. Drainage of much of this land will be necessary in order to render this as yet virgin land suitable and safe for cultivation. Drainage systems for this kind of land must necessarily be quite comprehensive in scope, and it would generally be impracticable for individual farmers to drain isolated farms, unless their lands are adjacent to the natural sloughs that traverse some parts of the area.

The actual and relative extent of the various grades of alkali soils, as determined during the progress of the survey, are given in the following table:

Areas of alkali land.

Grade.	Acres.	Per cent.
Less than 0.20 per cent	75,584	35.4
From 0.20 to 0.40 per cent	11,648	5.5
From 0.40 to 0.60 per cent	8,000	3.7
From 0.60 to 1 per cent	14,528	6.8
From 1 to 3 per cent	25,280	11.8
Over 3 per cent	78,592	36.8
Total	213,632	....

The alkali areas were located in the southern, western, and southeastern parts of the area surveyed, extending from 4 to 6 miles in all directions from Little Mountain. The only areas entirely free from alkali were in the northern end of the valley. The areas of greatest salt content were located chiefly in what was formerly part of Great Salt Lake and in the bed of Box Elder Lake. In these areas the average salt content for the first 6 feet is anywhere from 3.50 per cent to 10 per cent. All the alkali in the area owes its origin to the process of lake recession and concentration.

The alkali is composed principally of chlorides, by far the largest constituent being sodium chloride or common salt. There are also limited quantities of alkaline carbonates and hydrogen carbonates, but sulphates are very seldom found. The alkaline carbonates (black alkali) were found practically everywhere in very small quantities in both soil and subsoil, but with one or two exceptions tests showed less than 0.05 per cent. There are many local black looking alkali spots throughout the area that are commonly supposed to be chiefly alkaline carbonates, but tests never showed more than traces, the principal constituents being chloride and some bicarbonates. Generally the maximum salt content was found in the third or fourth foot section, but sometimes as deep as the sixth foot.

On account of the fact that the surface soil to a depth of 1 or 2 feet is very often comparatively free from alkali, a native growth of sagebrush, rabbit bush, flowers, and grasses often prevails where the average salt content for the first 6 feet of soil is from 1 to 3 per cent. By these conditions the people are often led to believe the soil is free from alkali. Where, however, such vegetation as young greasewood, samphire, salt grasses, etc., predominates, the alkali is not far below the surface.

Some data were obtained concerning the amount of alkali that crops in the valley would withstand. As the alkali conditions change more or less during the growing season, owing to surface evaporation, irrigation, etc., the data can not be regarded as absolute. Young wheat was found doing well with from 0.50 to 0.56 per cent of salt in the surface foot, and oats, while not doing so well, would apparently mature nicely.

During the spring, when sugar beets were young, tests were made at the root crowns of beets that seemed to be growing in their limit of alkali, and 1.52 per cent of soluble salt was found in the first foot. No examination of the second foot was made. Late in the summer the same field was visited, and it was found that beets were growing well and would mature in soil carrying from 2.50 to 4.70 per cent in the surface foot, with 0.42 to 0.84 per cent in the second foot. These were isolated beets growing in alkali spots that had killed out most of those planted. As the surface foot of soil carried more salt in late summer than in spring, when the field was first examined, and as the beets were well able to mature, it would seem that 1.50 per cent of alkali in the surface foot was not more than beets could endure. The fact that sugar beets were found growing in such a high percentage of alkali seems at first sight somewhat strange, but the amount of alkali in which a crop is found growing at any one time tells very little of the life history of that crop. Because sugar beets were found growing in from 2.50 to 4.70 per cent of alkali in the surface foot of soil late in summer does not argue that the same sugar beets would have been able to resist such quantities in their younger stage, and in fact they did not do so.

A heavy, well-matured crop of alfalfa was found growing in soil containing 0.14, 0.27, 0.43, 2.00, 3.12, and 3.75 per cent of alkali from the first to the sixth foot, respectively—an average of 1.62 per cent—with standing water at 4 feet. The water table was probably temporarily high owing to recent irrigation.

Owing to the recession of Great Salt Lake large areas of lake bottom land were found in the southern and southwestern parts of the area surveyed. The water was within 2 or 3 feet of the surface and the soil was excessively salty, containing more than 3 per cent in the first foot, with increasing amounts at greater depths. However, large tracts of this land support a heavy crop of sedge grass wherever Bear River overflows it copiously during the late winter and spring. Tests in heavy growths of this sedge showed from 3 to 5 per cent of alkali in the first foot, with increasing salt content in the subsoil. Large quantities of this grass are harvested for winter feed, and, while not a choice hay, it is fed to cattle until spring. Other grass is grown in small quantities on the same land, which makes it valuable for summer grazing. The following varieties, which were determined by Professor Spillman, promise to be of considerable value for such land: *Distichlis spicata*, *Polypogon monspeliensis*, *Scirpus maritimus* (sedge), and *Puccinellia airoides*. The last-named grass should be cultivated in preference to the coarse sedge, as it is much more valuable for feeding, though the yields are not so large.

BAKERSFIELD AREA, CALIFORNIA.

The Bakersfield area was surveyed in 1904 by Macy H. Lapham and Charles A. Jensen. It is situated near the extreme southern or upper extremity of the San Joaquin Valley. A considerable acreage is devoted to the growing of alfalfa, grains, vines, live stock, and dairy products.

The climatic conditions here approach closely those of a desert, with high summer temperatures, low relative humidity, and other climatic conditions promoting excessive evaporation.

The largest and most important part of the area consists of the Kern River delta deposits, composed largely of mountain wash of granitic material. In general the physiographic features resemble the Kings River delta, but the area slopes somewhat more abruptly to the southwest and lacks many of the open sloughs and stream channels. While the natural drainage slopes over the greater part of the area are sufficient readily to remove surplus waters, a few parts of the area, especially in the vicinity of the southeastern and southwestern margins, are deficient in natural drainage and heavily impregnated with alkali. The prevailing soils are sands and sandy loams, generally of fine texture, micaceous and porous. In the vicinity of the city of Bakersfield and along the eastern margin of the area a few soil types having adobe and heavy loam subsoils occur. All the soils of the area are, however, in general underlain by light and porous subsoils. Capillary and gravity movement of soil waters take place readily, especially in the fine micaceous sands frequently occurring in irregular or elongated, slightly elevated bodies or ridges.

No attempt is made to produce crops without the aid of irrigation. The water supply, which is taken from Kern River, with, in a few cases, an auxiliary supply derived by pumping from deep wells, is of excellent quality, but owing to the uncertain and limited supply a large proportion of the lands within the area surveyed are unirrigated and barren.

In the aggregate a large percentage of the soils of the area contained alkali salts in such quantities as to render them practically worthless for agricultural purposes. The alkali was distributed as irregular patches, bodies, and streaks, occurring chiefly upon the fine micaceous soils and river sediments of the delta lands lying south of Kern River. The slightly elevated ridges and patches of porous micaceous fine sands are especially liable to impregnation, possessing marked capillary properties, which under the influence of rapid evaporation quickly restores the bulk of the salts to the surface from the moist subsoils, into which they find their way as they are leached by irrigating waters from adjoining low-lying areas of soil. These minor elevations, lying above the reach of the irrigating waters, which are here applied by surface flooding and not by subirrigation, as in the Hanford area, thus become strongly impregnated with salts, which under the normal rapid upward movement in response to evaporation from the surface form a heavy crust or loose pulverulent alkali mulch, consisting of a mixture of soil grains and salt crystals, at or near the soil surface. The subsoils were, however, throughout the lighter soils of the area, frequently comparatively free from salts, even when salts occurred in the surface foot in concentrated form. In the vicinity of the eastern margin of the area surveyed, however, soil types occur of heavier texture, in which the alkali salts appeared in concentrations of from 1 to 3 per cent or over to the depth of 6 feet, or concentrated in a lime-carbonate-alkali hardpan encountered in the subsoils. Sodium carbonate, or black alkali, is of common occurrence in the Bakersfield area, and in fact seems to be of general occurrence whenever alkali salts in considerable amounts occur throughout the eastern side of the San Joaquin Valley. Frequent exceptions to this rule were to be found, as in the silt loam soils occurring southeast from the city of Bakersfield, which carried enormous quantities of alkali salts, chiefly of the sodium chloride variety, but were free from the more destructive carbonates.

There are no unusual or untoward conditions favoring the formation and presence of alkali salts in this area. In such regions of deficient rainfall and resulting restricted drainage the formation, by weathering of rock particles, of alkali salts in excess of the amount removed by scanty rains and flood waters is of general occurrence. In this area climate and topography do not favor the rapid removal of these substances. In fact, owing to the absence of more or less complete natural drainage channels, the soils are not favored by natural drainage facilities. Irrigation has here also resulted in the saturation of the subsoils and the raising of the water table. This, with the porous soils, capable of rapid capillary movement, furnishes sufficient cause for the concentration of alkali salts in the surface of slightly elevated porous soils which irrigation water does not reach and in the heavier soils and subsoils of sinks or local drainage basins. Furthermore, but little of the area is devoted to the growing of cultivated crops, which by frequency of cultivation tend to check evaporation and prevent the rise of the alkali salts. Upon the other hand, owing to the limited supply and to the greater cost of procuring and applying irrigating waters, greater enforced economy in the use of water is practiced.

While enormous quantities of alkali salts occur within the area, the most serious concentrations occur usually upon either those soil bodies of slight elevation which lie above the reach of the irrigating waters or else in more extensive tracts which are uncultivated and unirrigated for lack of water.

With the exception of a few cases in which heavy subsoils of dense structure occur, the salts seem to be leached readily into the porous subsoils with a few generous floodings and removed by natural drainage. Concentration contour lines are thus frequently very abrupt and distinct, depending upon the extent and frequency of cultivation and irrigation. A few irrigations and slight preliminary cultivations frequently seem to sweeten the lands enough for ordinary crops, and one may often see alfalfa fields free from alkali salts in any injurious amounts separated from tracts of too great concentration for any ordinary crop by only the width of a public roadway or by a line of fence.

Natural conditions of soil texture, structure, and topography over a great proportion of the area thus favor rapid reclamation of the alkali lands, which is, upon the other hand, opposed by a limited water supply. The opening of a few drainage ditches and the laying of occasional lines of drain tile would aid in removing the excess of salts and tend to permit the use of less water in the first washing of the salts from the soil.

Upon some of the soils of the eastern and southwestern margins of the area, in addition to lack of water supply, there is a deficiency in natural drainage. Were water available for irrigation and reclamation, the opening of a more extensive system of drainage, with the construction of extensive drainage ditches and perhaps the improvement of one or two incomplete natural drainage channels, would here be necessary in order to render the heavily impregnated alkali soils productive.

CANDO AREA, NORTH DAKOTA.

The Cando area was surveyed in 1904 by Elmer O. Fippin and James L. Burgess. This area is situated in the northeastern part of the State and contains 288 square miles. After the land was opened for settlement in 1883 the development for a period of years was quite rapid, but a succession of disastrous crop failures in the late eighties retarded the development. Since that time there have been favorable crop seasons and the area has become quite prosperous.

The average annual rainfall amounts to nearly 20 inches, the greater part of which falls during the growing season. The country consists of an undulating treeless prairie, slightly trough-shaped, with the lowest portion forming a broad, shallow valley. The elevation above sea level is approximately 1,500 feet, with a general southward slope.

The soils of the area are chiefly derived from glacial débris and consist principally of loams, with smaller areas of clay and fine sandy loam soils. As a rule, all of the soils of the area are quite rich in organic matter. Except in a few instances, alkali conditions are not serious and with proper methods of soil management will never seriously affect the productiveness of the soils. The rainfall is sufficient to prevent any marked accumulation of salts within the root zone of the soil. The accumulation of alkali salts that occurs is confined mainly to local spots in small depressions or in somewhat larger areas of poor drainage. The salts found in such places have been leached from the soil of higher-lying areas by the rain and retained there through obstructed drainage. Most of the salts in the Cando area are sulphates, analyses of the moist alkali spots revealing no sodium carbonate. The sulphates of calcium, potassium, magnesium, and the bicarbonates of the last three constitute the principal salts. Slight amounts of sodium chloride were also found.

To reclaim the worst alkali accumulations along the sloughs and coulées, surface drainage should be resorted to wherever possible. Underdrainage is usually impracticable, and in most cases unnecessary, because the only requisite is that the salts be kept below the zone of root action, and good surface drainage, with deep and thorough cultivation, accomplishes this result, since most of the crops grown are shallow rooted.

LABORATORY INVESTIGATIONS BY THE BUREAU OF SOILS.

In addition to the field investigations carried on by this Bureau considerable work has been done in its laboratories upon the relations of alkali and soils.

SALTS AS INFLUENCING THE RATE OF EVAPORATION OF WATER FROM SOILS.

Briggs[a] has investigated the effect of sodium chloride, sodium sulphate, and sodium carbonate in modifying the rate of evaporation of water from soils.

Three sets of experiments were made, as follows:

(1) The evaporation from moist soils spread out in thin layers in large trays was measured, some of the samples being moistened with normal salt solutions and others with distilled water to serve as

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[a] Field Operations, Div. of Soils, 1899, Report 64, Dept. of Agr. pp. 184–198.

checks. The soil in all the trays was stirred frequently in order to prevent the formation of any crust of salt. The object of this experiment was to determine whether the marked diminution of evaporation from alkaline soils, observed by Buffum, was due to surface conditions.

(2) The relative rate of evaporation in open dishes of pure water and of saturated solutions was measured as a check upon the conditions in the preceding experiment.

(3) The evaporation from the surface of soils packed in tall, narrow cylinders and moistened with pure water and with normal salt solutions was measured. This was a repetition of Buffum's experiments. This arrangement served to accentuate the formation of salt crusts at the surface. The soil used in all the experiments was a fine sand from James Island, S. C.

The results of the first experiment show that the soils moistened with normal solutions of salts lose their water by evaporation nearly as rapidly as soils moistened with distilled water, provided the soil is stirred occasionally, so as to prevent the formation of surface crusts. The evaporation from soils moistened with normal solutions of sodium chloride, sodium sulphate, and sodium carbonate was about 10 per cent less than when distilled water was used.

The results of the second experiment show that the evaporation from saturated salt solutions, in Petri dishes, averaged about 10 per cent less than evaporation from distilled water under similar conditions. These results agree well with those in the preceding experiment, showing that the diminution in evaporation under the conditions employed in that experiment was not influenced by the fact that the solutions were distributed over the surfaces of soil grains.

The results of the third series corroborated those of Buffum, showing that evaporation from soil columns moistened with normal salt solutions was only from 50 to 60 per cent of that from the cylinder moistened with distilled water. The results of the two preceding experiments show that this effect is much greater than can be attributed to the physical properties of the solutions, and that the greatly diminished evaporation in this case must be attributed to the formation of the crust of salt on the surface of the soil, which acts as a mulch.

For purposes of comparison, the evaporation was also determined from a cylinder moistened with distilled water but covered with a mulch of sodium sulphate. The evaporation from this cylinder was practically the same as from the cylinders in which the soils were moistened with solutions, showing again that the evaporation is controlled mainly by the surface conditions.

The conclusion drawn from these experiments is that the rate of evaporation from saturated solutions from the more common alkali salts is about 10 per cent less than in the case of distilled water, and that this is not changed when the solutions are distributed over the surface of soil grains, provided no crust is allowed to form during evaporation. When, however, evaporation takes place from an undisturbed column of moist soil containing a considerable quantity of salt solution the accumulation of salt at the surface acts as a mulch, which cuts down evaporation to about one-half of that taking place from a similar column of soil moistened with distilled water. The rate of evaporation is, therefore, in the case of alkali soils, dependent much more upon surface conditions than upon the physical properties of the salt solution. This statement must not be considered as applying to diminution of evaporation resulting from the formation of hardpan in the soil mass, which obviously depends upon the nature of the substances in the solution.

CAPILLARY STUDIES.

Briggs and Lapham (Macy H.)[a] have investigated the influence of the concentration of the soil solution upon the capillary rise of soil moisture.

Soil columns were held in glass tubes 2½ cm. in internal diameter, supported upon disks of fine brass wire gauze cemented to their lower ends. The lower end of each tube was immersed in the salt solution, the solution in each case being maintained at a definite level by a modified Mariotte apparatus. The salts investigated were sodium chloride, sodium carbonate, and sodium sulphate, and three concentrations of each were used, namely, one-half normal, 20 per cent, and saturated. In the case of the one-half normal solutions (corresponding to from 2.5 to 3.5 per cent by weight, depending upon the salt used) the height to which the solutions rose was practically the same as for distilled water. The capillary rise for saturated solutions of the sodium chloride and sodium sulphate was but little more than half of that observed for the one-half normal solutions. Sodium carbonate solutions in both cases rose higher than the solutions of the other salts. The actual rise observed for the fine sand in the case of the one-half normal solutions was about 37 cm. for sodium chloride and sodium sulphate and 40 cm. for sodium carbonate, while in the case of the saturated solutions the sodium chloride and sodium sulphate solutions gave a capillary rise of 21 cm. and the sodium carbonate solution 30 cm. The capillary rise of distilled water in this soil was 37½ cm.

Briggs and Lapham summarize the results of their paper as follows:

(1) Dissolved salts in general do not increase the capillary rise of soil waters.

(2) Neutral salts in dilute solutions have practically no influence on the extent of capillary action.

(3) Concentrated or saturated solutions of all salts materially diminish capillary activity.

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[a] Capillary Studies, Bul. 19, Bureau of Soils, pp. 5–18.

(4) This effect appears to be due—

(*a*) To the increased density of the solution, which more than offsets the increased surface tension; and

(*b*) To the resistance of a film to a tangential shearing stress, which retards capillary action and offers in addition a permanent resistance to the movement of the solution through thin films, thus increasing the angle of contact; or

(*c*) To an increase in the tension of the liquid-solid surface as the concentration is increased.

(5) Sodium carbonate differs from neutral salts, the capillary rise being considerably greater than for neutral solutions of equal concentration.

(6) This may be due in part to the saponification of traces of grease on the surface of the soil grains through the hydrolysis of the sodium carbonate, thus furnishing clean surfaces for capillary action.

(7) The same effect should consequently be observed with all salts which undergo an alkaline hydrolysis, viz, potassium and sodium carbonates, borates, phosphates, etc.

(8) This action is characterized in the soil tubes by indistinctness of the upper boundary of the capillary column.

The marked diminution in the capillary rise as the concentration increases serves to protect the soil to some extent from the accumulation of salt at the surface. The effect is then in the same direction as that found by Briggs in his experiments on the influence of dissolved salts on the rate of evaporation of soil moisture (see p. 139), where the rate of evaporation was shown to decrease as the accumulation of the salts at the surface increased. Too much weight must not, however, be placed upon these experiments made with dry soils, as Briggs and Lapham have shown (see p. 143) that the height through which capillary action will take place in a moist soil is much greater than the capillary rise in a dry soil.

A great number of experiments have been made upon the height to which water will rise by capillary action in different types of soils, and the results of such experiments have been used as a basis for computing the distance through which a given soil can lift water by capillary action from the water table to the surface. Such experiments have also been used in calculating the depth below the surface at which tile-drains must be placed in order to prevent capillary connection between ground water and the surface. However, Briggs and Lapham[a] have shown that the height through which capillary movement of water will take place in a moist soil as a result of evaporation at the surface is much greater than the height to which water will rise by capillary action in a dry soil and that, consequently, measurements made upon dry soils are inadequate for determining the height through which the soil can supply water to the roots of plants or the depth to which tile must be placed in order to cut off effectively the capillary connection between the water table and the surface of the soil. The true limit for capillary movement may be determined by finding the limiting height of the soil column from the upper surface of which evaporation is taking place at a measurable and approximately uniform rate, water being supplied at the same time from a reservoir at the base of the column of soil. For a fine sand it was found that the capillary rise in a dry soil was only 37 cm., while the limiting value of the capillary movement in a vertical column of moist soil was not less than 165 cm., or four and one-half times as great.

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[a] Capillary Studies, Bul. 19, Bureau of Soils, 1902, pp. 19–30.

NATURE OF SOLUTIONS.

Chemical analysis of the soluble salts found in arid regions yields rather remarkable results, for there is found a relatively large percentage of salts which are usually regarded as sparingly soluble—notably the sulphate and the carbonate of lime—and the question how they have been dissolved and transported in such large quantities is a natural one. When we attempt to dissolve these salts in water, in order to remove them from the soil, just such surprising solubility results are obtained, and in order to understand these phenomena it will be desirable to review the solution laws which apply to these cases.

Before discussing these laws it seems well to state more precisely what is understood by the term "solution," and as we are concerned only with solutions of solids in liquids we shall not stop to make any modifications which other solutions would necessitate.

The most striking characteristic of a solution is its homogeneity; that is to say, after it has come to equilibrium every part of the solution is just like any other part in all its physical and chemical properties. Two important exceptions should be noted here. If the solution be one of considerable height or depth the gravitation force comes in evidence, the lower portions of the solution are more dense, the higher portions less so, and there is a corresponding variation in other properties. But there is no sudden break in the properties, for they vary regularly and continuously from the top to the bottom. Again, it has been observed in the case of solutions in contact with solids (the walls of the containing vessel, for instance) that in portions very near the surface there is often a concentration of the dissolved material. This phenomenon has been called adsorption. Another important characteristic of a solution is that all its properties vary continuously with the concentration. These two properties just described are incorporated in the best definition as yet proposed for a solution, i. e., a homogeneous mixture whose properties vary regularly with the concentration.

It has been found convenient in discussing solutions to introduce certain terms, and, as it will greatly simplify what is to follow, they are here defined. The substance in which the solution takes place is known as the *solvent*, and the substance which goes into solution in the solvent is called the *solute*.

From the study of the phenomenon presented by solutions it has been shown that the solute is in a condition analogous to the gaseous condition, and just as a gas exerts a pressure on the walls of a containing vessel so a solute exerts a pressure on the walls of a containing vessel, through which the solvent is free to move. As the solute can not penetrate the walls of the vessel the tendency to equalize the conditions outside and inside the vessel must result in the passage of the solvent from the dilute to the more concentrated solution. The pressure which must be applied to a solution in order to prevent such a change in concentration is the *osmotic pressure*, and this osmotic pressure is found to be very nearly the same in amount as the vapor pressure would be at the particular temperature if the substance were a gas at that temperature. As the same law governs volume, temperature, and pressure of all gases irrespective of the nature of the gas, the obvious explanation advanced is that the structure of all the gases is quite similar, an explanation which is at the basis of the molecular theory. Thus equal numbers of molecules of different gases are supposed to occupy equal volumes, and hence the volume-pressure-temperature relations are dependent only upon the number of molecules involved.

Some of the properties of gases have been ascribed to solutes. The molecules of the solute are supposed to move freely among one another and to be independent of any specific characteristic of the molecule itself, and consequently they will move or diffuse throughout the solvent until the solution becomes homogeneous. In the case of a vessel with walls permeable to the solvent but not to the solute there is a pressure due to the unequal distribution of the molecules of the solute inside and outside the vessel. This pressure is dependent upon the volume, the temperature, and the number of molecules within the vessel, but is quite independent of the chemical nature of the molecule. Thus the laws which hold for gases also hold for solutions if we substitute the term "osmotic pressure" for "vapor pressure."

The solutions with which we most commonly meet, and those which will almost exclusively interest us, are those in which the solvent is water and the solute or solutes are salts; that is, substances formed by the action of an acid on a base. These substances, when dissolved, show wide variations from the laws which have just been described. These variations are, perhaps, best studied by a consideration of the osmotic pressures they exert, which are found in all cases to be higher than was to be expected. Furthermore, these pressures vary with temperature or concentration in a way entirely different from solutions in general. It was first pointed out by Arrhenius that these variations are characteristic of solutions of electrolytes; that is, solutions through which the electric current passes. By making use of a hypothesis which had been advanced by Clausius the phenomena were readily explicable. Clausius was led to assume that when an electrolyte is dissolved in water it separates, partially at least, into components or, as we now say, it dissociates. These dissociated parts are chemical equivalents, and in the act of dissociating develop equivalent amounts of electricity with different signs. Thus sodium chloride would dissociate into sodium, bearing a certain amount of electricity with the positive sign; and a chemically equivalent amount of chloride, bearing an equal amount of negative electricity. In the notation of chemistry this is expressed:

$$\mathrm{NaCl} \rightleftarrows \overset{+}{\mathrm{Na}} + \overset{-}{\mathrm{Cl}}.$$

In an exactly similar manner sodium sulphate would dissociate as thus indicated:

$$\mathrm{Na_2SO_4} \rightleftarrows \overset{+}{\mathrm{Na}} + \overset{+}{\mathrm{Na}} + \overset{=}{\mathrm{SO_4}}$$

the negative electricity on the group SO_4, or sulphion, exactly equaling the positive electricity on the two sodium equivalents.

Borrowing an expression introduced by Faraday, these dissociated parts *with their electric charges* are called *ions*. When the solution containing ions is put in an electric circuit, the ions bearing the positive charges are attracted to the negative pole of the circuit and the ions bearing the negative charges toward the positive pole, in accordance with the well-known law of electricity.

The chlorine ions on arriving at the positive pole give up their electric charges, thus becoming ordinary chlorine, which escapes as the well-known gas or reacts on the water of the solvent to form hydrochloric acid and oxygen, which escapes as a gas. In a similar manner the sodium ions discharge their electric burdens, thereby becoming ordinary sodium, and immediately react on the water to form sodium hydroxide and hydrogen. It is to be observed, however, that the chemical behavior becomes entirely different as soon as the ions lose their electric charges. The illustration just used indicates that there would be a gradual accumulation of hydrochloric acid at the positive pole and of sodium hydrate at the negative pole. This is what actually happens, as anyone can readily test by drawing off portions of the solution near the poles and analyzing them.

Each of these ions in solution behaves to all intents and purposes as an individual molecule and exerts its influence as such in determining the osmotic pressure in the solution.

Without going into details, it may be said that from an estimation of the osmotic pressure it is possible to determine the number of ions in a given solution. From the conductivity it is also possible to determine the number of ions; and the agreement by both of these methods is of such a character as to make this idea of electrolytic dissociation or ionization a good working hypothesis.

Just as the osmotic pressure of any solution is proportional to the concentration of molecules or ions, so the other physical properties of solutions are proportional to the concentration. By "concentration" we mean the total number of dissociated molecules and of ions per volume unit of the solution. The lowering of the freezing point, the rising of the boiling point, the lowering of the vapor pressure are all directly proportional to the concentration of the solution.

Suppose a solution of a salt, for example sodium chloride, be brought in contact with another salt, such as potassium nitrate. There will then be in the solution not only the sodium chloride and the potassium nitrate, but the ions formed from them, which may be represented thus:

$$\mathrm{NaCl},\ \mathrm{KNO_3},\ \overset{+}{\mathrm{Na}},\ \overset{+}{\mathrm{K}},\ \overset{-}{\mathrm{Cl}},\ \text{and}\ \overset{-}{\mathrm{NO_3}}.$$

But the $\overset{+}{\mathrm{Na}}$ ions and $\overset{-}{\mathrm{NO_3}}$ ions can form sodium nitrate and will form it to a certain extent, so that we shall have this salt also in the solution. In the same way potassium chloride will be formed and the final state of the solution will represent an equilibrium between the solvent water and the various salts and ions which can be formed. It is obvious that the same condition could be obtained by starting with sodium nitrate and potassium chloride; and the equilibrium could be displaced one way or the other by varying any of the constituents. Such a reaction is called *reversible*. Again, sodium chloride in water partially dissociates thus:

$$\mathrm{NaCl} \rightleftarrows \overset{+}{\mathrm{Na}},\ \overset{-}{\mathrm{Cl}}.$$

But if the concentration be altered by the addition or evaporation of water, the equilibrium is displaced and either more sodium chloride will dissociate or more will be formed from the already dissociated ions. In fact, practically all simple reactions so far studied, whether in solution or otherwise, have been found to be reversible.

Suppose a reversible reaction between A and B with the formation of C and D. It may be expressed thus:

$$A + B \rightleftarrows C + D.$$

Let p, q, r, s represent the active masses or the number of molecules per unit volume acting, respectively.

Let K be the rate of combination of unit masses of A and B to form C and D, and

Let K_1 be the rate of combination of unit masses of C and D to form A and B.

The magnitude of the reaction $A + B \rightarrow$. is Kpq, for it is directly proportional to the rate of combination and to the active masses, and it will be K_1rs for the reaction $C + D \rightarrow$. Therefore when equilibrium is established

$$Kpq = K_1rs. \qquad (1)$$

This is known as the law of "mass action," or of Guldberg and Waage. It is conventional to take as the unit of active mass in solutions one reacting weight per liter.

Applying this formula to the case just cited,

$$NaCl \leftrightarrows \overset{+}{Na} + \overset{-}{Cl},$$

we would have

$$K_1pq = K_2r,$$

where p represents the concentration of the ion $\overset{+}{Na}$, q that of the ion $\overset{-}{Cl}$, and r that of the undissociated salt NaCl. From which

$$\frac{pq}{r} = \frac{K_2}{K_1} = K, \qquad (2)$$

which is known as the dissociation or ionization constant, and is a constant for constant pressure and temperature, but is different for different salts.

For those acids and bases and their salts which are usually characterized as strong, K is found to be large, while on the contrary it is always small for the so-called weak acids, bases, and their salts. Since it is obvious that it is the active masses of the ions which make an acid or base weak or strong, the magnitude of K is generally taken as the measure of the relative "strength" of an acid or base at the present time.

Still applying formula (2) to such a case as

$$NaCl \rightleftarrows \overset{+}{Na} + \overset{-}{Cl},$$

we see that for every $\overset{+}{Na}$ ion there will be a $\overset{-}{Cl}$ ion—that is, the concentration or active mass will be the same, and

$$\frac{p^2}{r} = K \text{ or } p_2 = Kr,$$

therefore the concentration of the undissociated salt is proportional to the square of the concentration of the dissociated salt. From which it follows that the greater the dilution the greater the proportion of dissociated to undissociated salt.

So far we have considered only cases of homogeneous equilibria where we had but one reversible reaction and complete solution. But there are certain types of heterogeneous equilibria which remain to be considered.

Suppose a solid salt, S, in contact with a solution saturated with respect to it. The salt which has gone into solution is partially dissociated into the ions A and B. In this case we are dealing with two equilibrium phenomena, the equilibrium between the solid salt and the undissociated salt in solution, and the equilibrium between the undissociated salt in solution and the dissociated salt in solution. The latter equilibrium is expressed in the equation

$$\frac{ab}{c} = K,$$

where a and b are the concentrations of the ions, and c that of the undissociated salt. But, as there is solid salt present, the concentration of the undissociated salt is constant, and the above equation becomes

$$ab = K_s,$$

where K_s is known as the "solubility constant."

The effect of the addition of a salt to a saturated solution of another salt may be predicted from the above equation. Suppose that a salt which in solution yields a common ion be added; for instance, let us add potassium chloride, which yields ions $\overset{+}{K}$ and $\overset{-}{Cl}$, to a saturated solution of sodium chloride, which yields the ions $\overset{+}{Na}$ and $\overset{-}{Cl}$. There is a tendency to increase K_s for sodium chloride, for the concentration of one of the ions, $\overset{-}{Cl}$, has been increased. As the value K_s is constant, the concentration of the other ion (Na) in the solution must decrease, and this is effected by a precipitation of sodium chloride. Thus, the effect of the addition of a salt which yields a common ion is in general to decrease the solubility of the other salt.

Suppose, on the other hand, that to a solution containing an electrolyte another containing no common ion be added. As has been already illustrated, there will be at once the formation of all the combinations possible to the ions, and with the consequent taking away of the ions for this purpose there will be a lowering of the product of ionic concentration for each of the salts; that is, the solubility will be increased. This phenomenon is most strikingly illustrated in the case of those salts usually regarded as insoluble. For instance, gypsum, which is essentially the salt calcium sulphate containing some water, is sparingly soluble in water. But the addition of an electrolyte with no common ion, such as sodium chloride, will considerably increase the solubility of the gypsum. So far as is known the addition of any electrolyte with an uncommon ion always increases the solubility of gypsum, for moderate amounts of the salt added, and the addition of an electrolyte with a common ion, such as a calcium salt or a sulphate, except, perhaps, in the case of sulphuric acid, always depresses the solubility of gypsum for moderate amounts of the salt added.

Water is itself a very weak acid with a very low ionization constant, but it does dissociate to a very limited extent into hydrogen and hydroxyl ions, thus:

$$H_2O \rightleftarrows \overset{+}{H} + \overset{-}{OH}.$$

These dissociated ions from water will of course react with the ions of the dissolved electrolyte, thus:

$$NaCl + HOH \rightleftarrows NaOH + HCl,$$

but the ionization constants of the sodium hydrate and the hydrochloric acid are very large, while that of water is relatively very small indeed, so that the latter will be formed and precipitated as such nearly completely, and the total effect will be so small as to be incapable of detection by ordinary methods. This will be true for any electrolyte with high ionization constant, but with an electrolyte which ionizes to a small degree the effect becomes important. Sodium carbonate has a very low ionization constant in water. The reaction is indicated thus:

$$Na_2CO_3 + HOH \rightleftarrows NaOH + HNaCO_3,$$

and while the acid sodium carbonate does dissociate further it is to a very slight extent, as is the dissociation of the sodium carbonate and water as compared with the dissociation or ionization of the sodium hydrate; in consequence, the solution behaves as though it were, as in fact it is, a solution of sodium hydroxide. This phenomenon of the dissociation of the salt of a weak acid or a weak base in water, with the formation of the corresponding strong base or acid possible, has been called *hydrolysis*. The ionization of water is increased by heating, a fact of importance in many analytical operations. It can be very beautifully illustrated with calcium carbonate. If powdered marble be shaken up with water it dissolves to a very slight extent and is hydrolized with the formation of calcium hydrate, which can be shown by the alkaline reaction with a few drops of phenolphthalein. On heating the color becomes very greatly intensified, but on cooling it gradually returns to its former condition. This increased hydrolytic power of heated waters is obviously of the first importance in studying geological problems involving the solution of such weak salts as carbonates, silicates, aluminates, and borates.

CLASSIFICATION OF ALKALI SOILS.

The various salts composing the alkali vary greatly in solubility. The more soluble salts will naturally go into solution more readily and rapidly than the less soluble ones. It will be convenient to consider the various phases of alkali presented to our attention as the results of the action of aqueous solutions of certain soluble salts upon less soluble salts.

Alkali has been conveniently classified as white and black, and this classification has been a very useful one in the past and is yet in some ways a convenient one, although it is often very unsatisfactory. For many purposes a classification based more specifically upon the chemical characteristics of the alkali or system of salts present would be preferable. That such classification can readily be made it is hoped will become evident as this paper proceeds.

PECOS TYPE.

From a general inspection of the analyses of the water-soluble constituents of the soils and crusts of the alkali areas, together with a study of the conditions in the field, it would appear that the nature of the alkali in any particular area has predominating features which may be considered as characterizing and differentiating it from other alkalies. In the Pecos Valley, New Mexico, it has been made very evident that the predominating feature is the contact of waters carrying considerable quantities of sodium chloride with the gypsum found abundantly in the soil, the gypsum, in fact, being in some places the main component of the soil. The sodium chloride, being so much more soluble, will be taken up long before the gypsum is appreciably affected, and we are therefore justified in regarding this problem as the action of aqueous solutions of sodium chloride upon gypsum ($CaSO_4 . 2H_2O$) or the dihydrate of calcium sulphate.

In aqueous solutions a reaction takes place between gypsum and sodium chloride, which may be represented thus,

$$CaSO_4 + NaCl \rightleftarrows Na_2SO_4 + CaCl_2,$$

part of the calcium and sulphions of the sparingly soluble calcium sulphate being converted into calcium chloride and sodium sulphate, compounds much more soluble than gypsum. If the solution were saturated with respect to gypsum by being kept in contact with this substance, more of the gypsum in the solid phase would go into solution to restore the equilibrium between the solid gypsum and its solution, which had been disturbed by the withdrawal of some of its component parts or ions to form sodium sulphate and calcium chloride. In other words, the gypsum becomes more soluble on account of the presence of sodium chloride and the solution more concentrated with respect to the total salts dissolved.

By the movement of the solution through the capillary spaces of the soil and the evaporation of the water at the surface the salts are brought toward the surface of the soil. If the solution becomes saturated before it reaches the surface, separation of solid salts will take place, but in any case the tendency will be toward the formation of a crust of the dissolved salts on the surface of the soil as they separate from solution on the evaporation of the water. The various salts on separating are more or less well crystallized, with the exception of the calcium chloride, which, on account of its great hydroscopiscity, is dehydrated only under extreme conditions and probably never separates in well-defined crystals in the field. It is evident that if water be added to the crust, the rate at which the several components will redissolve is dependent not only on their respective solubilities, but also very largely on their physical states, whether in large, well-defined crystals, exposing a relatively small surface to the solvent action of the water, or in a fine, pulverulent condition, thus exposing a very large surface to the action of the solution, etc. The calcium chloride would evidently go into solution more quickly than any other component of the crust. If the water were allowed to stand in contact with the crust for a sufficient length of time, all the salts would dissolve, to a greater or less extent, until a state of equilibrium was reached; but this is not what takes place when water is added, either by irrigation or by rain. It has been pointed out that the downward movement of such waters in the soil is quite rapid and is through the larger soil spaces, in contradistinction to the slow, upward movement of these waters through the capillary soil spaces; consequently on the addition of water to the soil or crust the calcium chloride, which goes into solution so much more rapidly than the other salts, is rapidly leached out and carried far down into the lower depths of the soil. When evaporation again sets in at the surface the calcium chloride, which has been carried so far below the other salts, either fails to reach the surface altogether or does so in lessened amounts. Thus it is that we practically never find calcium chloride and sodium sulphate in the crust in equivalent amounts, as we should expect a priori on the basis of the reaction between sodium chloride and calcium sulphate with the formation of some calcium chloride and an equivalent amount of sodium sulphates. Moreover, if the rate of movement of the different salts in the capillary spaces of the soil, after the salts have gone into solution, be different for different salts, it is incredible that the differences could be of such magnitude as to affect materially those features of the phenomena which have just been considered.

The calcium chloride which has been washed down into the subsoil accumulates there in certain places, and then on prolonged drought is sometimes brought to the surface in very large amounts in spots of limited area. On account of its well-known and very great property of deliquescence it keeps the surface where it has accumulated quite damp, even during periods of protracted drought. This gives a darker appearance to the soil where the calcium chloride has accumulated than that of the surrounding drier areas where this salt has not accumulated, these darkened areas being locally known in the Pecos Valley as black alkali spots, although chemical examination shows them to be quite free from soluble carbonates.

The metathesis or interaction of calcium sulphate and sodium chloride is the predominating feature of the alkali in the Pecos Valley. It is modified to some extent by the presence of other salts, as the salts of magnesium, for example; but the latter are always present in much smaller quantities than are the calcium and sodium salts. Soluble carbonates are almost entirely absent and merit no attention in this area. As the Pecos area was the first of the gypsum-sodium chloride type to receive extended investigation by this Bureau, it has been proposed to classify areas in which the interaction of gypsum and sodium chloride is the predominating feature under the heading "Pecos type."

FRESNO TYPE.

It has become evident that in the area about Fresno the prevailing feature of the alkali problem from the chemical point of view is the contact of aqueous solutions of sodium chloride with calcium carbonate. Large quantities of calcium carbonate are found in the soils of this area. Frequently it is the cementing material for more or less extensive beds of hardpan at various depths, usually a few feet below the surface and generally parallel to it. The sodium chloride in solution, on being brought into contact with calcium carbonate, reacts at once, as thus indicated:

$$CaCO_3 + NaCl \rightleftarrows Na_2CO_3 + CaCl_2$$

calcium chloride being formed as in the Pecos type, but sodium carbonate being the other constituent instead of sodium sulphate, as in the area last considered. The same general considerations apply here. The salts are brought to the surface by evaporation of the solvent and the movement of the solution through the capillary spaces of the soil. They are then, on the addition of water at the surface, partially dissolved and carried quickly down, the calcium chloride being more rapidly removed than the other salts during the process.

The study of this type presents some specially interesting phenomena. As has been pointed out elsewhere, the action between the calcium carbonate and the sodium chloride is much facilitated by the presence of carbon dioxide, this substance reacting with the calcium carbonate to form the much more soluble bicarbonate or hydrogen carbonate, and this latter substance then reacting with the sodium chloride. The reaction then would be expressed thus:

$$Ca(HCO_3)_2 + NaCl \rightleftarrows CaCl_2 + NaHCO_3.$$

The sodium hydrogen carbonate thus formed would be brought to the surface, and in much greater amounts than if the normal calcium carbonate had been its origin. On desiccation, the sodium hydrogen carbonate would be very largely inverted to the normal carbonate. In such areas the production of black alkali is notoriously great, for it is well known that soil grains have the power of condensing very considerable quantities of carbon dioxide, the soil thus containing much more of this agent than one would suppose from its very small partial pressure in the atmosphere above the soil, and wet or dry areas containing much organic matter are especially adapted to the formation and retention of carbon dioxide.

The presence of magnesium carbonate with the calcium carbonate, as is frequently the case in soils of this class, introduces some modifications as to degree in the formation of soluble carbonate; for magnesium carbonate is more soluble than calcium carbonate, and therefore its active mass would be greater. Therefore the contact of magnesium carbonate with sodium chloride would be expected to yield soluble carbonates more readily and in much greater amount than would the calcium carbonate alone. These views are fully substantiated by the investigation of certain alkali soils from California containing much lime-magnesium carbonate.

The occurrence of calcium chloride spots is quite common in this area. Usually there is also a small amount of soluble carbonates or bicarbonates present. When the calcium chloride is large in amount, the amount of soluble carbonate is quite small, and not infrequently disappears altogether; for calcium carbonate, being quite insoluble as compared with the other salts present, and likewise being but little dissociated, would be formed and precipitated as such. In such spots the application of water to the surface will first wash the excessive amount of calcium chloride away, and then the calcium carbonate will in turn react with the sodium chloride to re-form sodium carbonate. The formation of small amounts of black alkali may well be expected as one of the first results of irrigating such spots. With good drainage, however, the evil would be but a temporary one.

In areas of this type are occasionally found small deposits of nitrates. This is to be expected, for here the nitrifying organisms find calcium carbonate to neutralize the excess of nitric acid formed, and their functions are thus not interfered with and kept down to a low limit by an accumulation of their own product.

Since Fresno is the first area in which these relations have been carefully studied and in which they are not disguised to any considerable extent by the presence of other salts, it is proposed to designate alkali areas of the calcium carbonate-sodium chloride class as belonging to the Fresno type.

SALT LAKE TYPE.

The type of alkali most commonly met is one in which the conditions observed may be regarded as the result of the action of aqueous solutions of sodium chloride upon calcium carbonate (or calcium hydrogen carbonate) and gypsum simultaneously. By the action of the sodium chloride upon the calcium carbonate some sodium carbonate would be formed, and also an equivalent amount of calcium chloride. By the action of the sodium chloride upon the gypsum sodium sulphate would be formed, and again an equivalent amount of calcium chloride. This second reaction would take place in the direction of the formation of calcium chloride to a greater extent than the first, for the sulphates are stronger electrolytes than the carbonates, and, moreover, the solubility of the gypsum is probably in most cases greater than the solubility of the lime carbonate, even though there be much carbon dioxide present. The formation of the common product, calcium chloride, would tend to retard both reactions in the direction of the formation of this substance, but more the one involving the calcium carbonate. The formation of the corresponding sodium carbonate is therefore very much lessened by the presence of the gypsum, a fact which has long been known empirically and which has been sometimes employed in the amelioration of the conditions in land containing black alkali by the addition of gypsum, or land plaster. The reaction between the gypsum and the calcium carbonate would simply result in lowering the solubility of both salts, because they yield a common ion, but the effect would be much more marked in the case of the carbonate, both on account of its being a weak electrolyte and of its lesser solubility. Therefore the amount of the lime carbonate in the solution, or its "active mass," is much lessened, with a corresponding lessening of the extent to which it can react with the sodium chloride to form sodium carbonate.

It must be remembered that the rôle of carbon dioxide is probably of great importance in this connection. The amount of this substance in the soil atmosphere may be quite large, and in consequence the solubility of the lime carbonate may be considerably increased by the formation of the hydrogen carbonate. This might well increase somewhat the amount of sodium carbonate formed and at the same time lessen to some slight extent the formation of sodium sulphate. This is a matter of great importance, for it indicates that in this mixed type of alkali some soluble carbonates are to be expected, although the amount will be small and may usually be neglected in an economic consideration of the area involved; but in the case of the application of gypsum for the correction of black alkali, the relative proportion of gypsum applied to the salts already present is small. It may be expected to fulfill its rôle temporarily by acting on the soluble carbonates in immediate contact with it; but an increase of the soluble carbonates by more of this material coming to the surface from lower depths or by its formation from an increased solubility of the lime carbonate through an increase in the carbon dioxide dissolved in the ground solutions will require further additions of land plaster. Therefore this method of ameliorating black alkali can be regarded as but a temporary expedient, and has the further disadvantage that the action of the sodium chloride upon the gypsum results in an increase of the soluble salts in the soil. On the other hand, the presence of a large proportion of soluble lime salts has the apparent effect of enabling plants to withstand much larger quantities of other salts than would be possible in the absence of calcium from the soil solutions.

The characteristics of this type of alkali are, then, the presence of soluble chlorides, sulphates, and the relatively small but varying amounts of soluble carbonates. The first area containing this type of alkali that received detailed attention from this Bureau was in the Salt Lake Valley, Utah. The type is therefore tentatively designated as the Salt Lake type.

MODIFIED TYPES.

At Tempe, Ariz., it appears that the original conditions are very similar to those at Fresno, Cal., in that the principal reaction involved is the one between sodium chloride and calcium carbonate. But the investigations of Professor Forbes, of the Arizona Experiment Station, and of Mr. Means, formerly of this Bureau, have shown that considerable amounts of soluble sulphates are constantly being added to the soils through the application of irrigating waters carrying rather large amounts of these substances in solution. The result is gradually to modify the original type of alkali, making it more nearly resemble the Salt Lake type, although the amount of lime sulphate formed in the soil is hardly sufficient to justify a reclassification under this latter heading. The area is rather to be regarded for the present as a modification of the Fresno type.

In the virgin soils of this area, or in those very recently brought under irrigation, the formation of soluble carbonates has frequently been noticed; but in those soils which have been irrigated for some time with the sulphate-carrying waters the occurrence of soluble carbonates in more than traces, or practically negligible amounts, has been found to be unusual. These observations are entirely in accord with the ideas developed above.

In the valley of the Sevier River, Utah, the alkali areas are of unusual interest, the alkali being essentially of the Fresno type. The soils are uniformly underlain by sandy formations, giving good natural underdrainage, and hardpan areas are, therefore, unusual. Even in the virgin soils the amounts of alkali are never very large, and in the irrigated areas, as might be expected with good underdrainage, the amounts of alkali are considerably diminished.

It has been found by Mr. Gardner, of this Bureau, that in the virgin soils of this area there are considerable amounts of soluble normal carbonates, but as the total amounts of soluble salts decrease in the soils the carbonates decrease also, the proportion of hydrogen carbonates to normal carbonates greatly increasing. This is in entire accord with the laboratory observations of Cameron and Briggs[a] on the equilibrium between carbonates and bicarbonates in aqueous solution. It was found that seepage waters fresh from these soils contained, as a rule, no normal carbonates, although always containing some hydrogen carbonates. If these waters be allowed to stand in contact with air for a while, either in pools or by running in the river courses or canals, so that they more nearly approach equilibrium with the air, there is always a partial inversion of the hydrogen carbonate to normal carbonates, as evidenced by the reaction of the solutions toward phenolphthalein.

These observations have an important bearing on alkali studies, as they show most clearly that not only is underdrainage of great importance in diminishing the actual amount of alkali in the soil, but that where there is black alkali this much dreaded substance is at the same time very largely changed to the much less noxious hydrogen carbonate. The change becomes the more nearly complete as the total amount of soluble material decreases.

BILLINGS TYPE.

In the valley of the Yellowstone, in Montana, a distinctly different type of alkali is found.[b] There the alkali consists almost entirely of sulphates, only traces of chlorides being found. While soluble carbonates occur, as has been amply demonstrated in the laboratory of this Bureau by examinations of crusts collected near Billings, they are always in very small amounts, which can practically be disregarded in a consideration of the problems presented by this area. Crystals of gypsum are abundant in the Yellowstone soils and in the rocks from which these soils are formed. Occasionally the gypsum is associated with relatively small calcium carbonate deposits. Sodium or magnesium sulphate, the most common of the soluble salts of this area, would decrease the solubility of gypsum because they furnish a common ion in the SO_4 group. They would react to some extent with calcium carbonate, making it more soluble, according to the following scheme:

$$Na_2SO_4 + CaCO_3 \rightleftarrows Na_2CO_3 + CaSO_4.$$

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[a] Bul. 18, Division of Soils, U. S. Dept. Agr., 1901.

[b] The Alkali Soils of the Yellowstone Valley. By Milton Whitney and Thomas H. Means, Bul. 14, Division of Soils, U. S. Dept. Agr., 1898.

From the well-known properties of the individual salts it could be prophesied, what is actually found to be the case, that equilibrium in this system is reached when the reaction is mainly from right to left. In other words, the solubility of calcium carbonate is but slightly increased in the presence of sodium sulphate. In the presence of carbon dioxide, and the consequent formation of calcium bicarbonate or hydrogen carbonate, the reaction is much further displaced to the right, as indicated by the above scheme. On desiccation at the surface the sodium hydrogen carbonate would mainly invert to the form of the normal carbonate, and in the presence of so much gypsum and magnesium sulphate as is always present in these soils it would be quite rapidly converted to the slightly soluble alkaline earth carbonates and sodium sulphate.

Practically the only salt to be considered in this area is sodium sulphate and possibly in some cases magnesium sulphate. It would appear that the Fort Benton shales, from which a large portion of the soils of this valley are derived, contain considerable quantities of sulphide of iron as marcasite or pyrites. On weathering this material is superficially oxidized to the very soluble ferrous sulphate. By further oxidation and hydrolysis the major part of the iron is precipitated as the very slightly soluble ferric hydrate, this substance then becoming more or less mixed with carbonate of iron by absorption of carbon dioxide. Hydrated carbonate of iron has been identified in some of the samples from this locality now in the collection of the Bureau. At the same time that the ferric hydrate was precipitated free sulphuric acid must have been formed. This acid was quickly neutralized by its action upon the other mineral components of the soil, especially lime carbonate. It would seem probable that this process is in large part responsible for the sulphates so abundant here.

ALKALI IN HUMID REGIONS.

There are several cases on record where alkali salts have been found in the soils of humid regions in such proportions as to kill vegetation during dry weather. Such alkali patches have been observed in one of the fields of the Maryland Experiment Station at College Park, Md. Samples taken from the surface of the soil to a depth of one-eighth of an inch on analysis showed 1.83 per cent of water soluble solids, mainly the nitrates of calcium, magnesium, sodium, and potassium, together with some of the chlorides and sulphates. The analysis of a crust from the surface of a soil near Starke, Bradford County, Fla., showed 0.19 per cent water-soluble salts, mainly sodium chloride, but in part sulphate and phosphate. Both these samples were found on a compact smooth surface, from which evaporation was much more rapid than from the surface of the surrounding soils. The accumulation of water-soluble salts at the surface of the soils (after long-continued dry spells) has also been reported near Cumberland, Md., near Durant, Miss., near Houston, Tex., and at a number of other places in humid areas.

RELATIONS BETWEEN ALKALI AND VEGETATION.

In a paper on Some Mutual Relations between Alkali Soils and Vegetation,[a] Kearney and Cameron have investigated the effect upon seedling plants of certain components of the alkali salts. The plants which they selected for experiment were the white lupine (*Lupinus albus*) and alfalfa (*Medicago sativa*). They have determined for each of the salts the limit of concentration in which the root tips of young seedlings of white lupine could just survive, as follows:

Concentrations in which seedling roots can just survive.

Name of salt.	Concentration, parts per 100,000 of solution.	Name of salt.	Concentration, parts per 100,000 of solution.
Magnesium sulphate	7	Sodium chloride	116
Magnesium chloride	12	Sodium bicarbonate	117
Sodium carbonate	26	Calcium chloride	1,377
Sodium sulphate	53		

Experiments were made to ascertain the limit of endurance of seedlings of alfalfa, and although the absolute limits were not determined they appear to be lower for every salt than in the case of white lupine. Thus for magnesium sulphate the limit appears to be between 0.0006 and 0.0012 normal, while for magnesium chloride the limit is between 0.0012 and 0.0025 normal. From these results the conclusion is drawn that it is the basic radical rather than the acid radical of the salt which chiefly determines their relative toxicity.

In other words, the cations derived from these salts are very much more active in their effect upon plant tissues than are the anions. This is strikingly brought out by a comparison among themselves of the three chlorides of magnesium, sodium, and calcium, on the one hand, and of the chlorides and sulphates of magnesium and sodium, respectively, on the other. In the former case, although the anions (Cl) are identical in kind, we find magnesium chloride eight times as toxic as sodium chloride and one hundred times as toxic as calcium chloride. In the latter case, magnesium sulphate is only twice as toxic as magnesium chloride, while sodium sulphate is little more than two and one-half times as injurious as the corresponding chloride.

A comparison of the seven salts above enumerated in regard to the degree of concentration of each in which absolutely no elongation of the roots occurred during twenty-four hours is interesting, as illustrating how far this point is removed from that of the minimum concentration which is still toxic. It will be seen that the position of the salts in this scale does not at all correspond with their sequence in the table of limits of endurance. In many cases, especially when the solution was still more concentrated, not only no increase of length but a positive shrinkage of 0.5 to 2 mm. was detected.

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[a] Report No. 71, U. S. Dept. Agr. (1902).

Concentration of solutions in which no growth in roots took place in a period of twenty-four hours.

Name of salt.	Concentration, parts per 100,000 of solution.	Name of salt.	Concentration, parts per 100,000 of solution.
Sodium carbonate	260	Sodium sulphate	1,410
Sodium bicarbonate	417	Calcium chloride	1,652
Magnesium chloride	960	Magnesium sulphate	1,680
Sodium chloride	1,160		

It is impossible to reconcile this sequence, as compared with that of the table on page 158, with the notion that the injurious effect of these salt solutions is merely a function of their osmotic pressures. If any fresh evidence were needed to disprove this assumption it is afforded by the fact, very clearly brought out in the present investigations, that marked toxic effects frequently appear long before loss of turgor has manifested itself or cessation of growth has occurred. It is certain that no useful conclusions as to the degree of toxicity of a solution can be drawn from its osmotic pressure.

Besides the above easily soluble salts a few others were experimented upon—the sulphate of lime and the carbonate of lime and magnesia. In solutions in which these were present, gypsum in excess and calcium carbonate in excess, the plants grew decidedly more vigorously than in pure water. With a solution of calcium carbonate in saturated solution of carbon dioxide the roots grew only one-third as fast as in distilled water. Magnesium carbonate, which in solution gave a strong alkaline reaction with phenolphthalein, allowed the roots to grow about as rapidly as in distilled water, but when carbon dioxide was added in excess to this solution, which gave now no alkaline reaction, the roots made no growth during twenty-four hours.

Pure solutions of the salts dealt with are shown to be generally injurious to plants, and this largely by virtue of the cations which they yield, as a comparison of the position of the several salts in the table of toxicity in pure solutions shows conclusively. Thus magnesium salts, irrespective of the character of their anions, are much more injurious than is any sodium salt, while the three chlorides (of magnesium, sodium, and calcium) differ enormously in toxicity, regardless of the fact that they yield a common anion.

Upon comparing the limits of endurance for lupine roots in pure solutions of the "alkali" salts with the limits determined by the methods employed in a field survey, it became obvious that the former were vastly lower than the latter; and that furthermore the order of toxicity of the several salts as fixed by investigators in the field differed greatly from that obtained by experiments in the laboratory. This was strikingly the case with magnesium sulphate, which is decidedly the most toxic of the seven salts when alone in a pure aqueous solution, but which is regarded as the least injurious by students of alkali soils. But it was recalled that none of these salts usually occurs in any notable quantity in the soil save in the presence of one or several others, both of the readily soluble salts and of the comparatively insoluble magnesium carbonate, calcium carbonate, and calcium sulphate. The key to the discrepancy appeared therefore to lie in mixtures of the various salts, and the study of these became logically the next step in the investigation.

The following table shows the results of experiments with Lupinus in solutions of magnesium sulphate with other salts added:

Limits for magnesium sulphate in mixtures.

Name of salt added.	Greatest endurable concentration of magnesium sulphate.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 of solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.00125	7	....	....
Magnesium chloride	.000625	3.5	0.0025	12
Sodium carbonate	.00125	7	.0025	13
Sodium sulphate	.00375	21	.01	80
Sodium chloride	.0075	42	.015	87
Calcium chloride	.2	1,120	.2	1,101
Magnesium carbonate	.01	56	Saturated.	Saturated.
Calcium carbonate	.02	112	Saturated.	Saturated.
Calcium sulphate	.6	3,360	Saturated.	Saturated.
Calcium sulphate and calcium carbonate	.4	2,240	Saturated.	Saturated.

In the light of figures given above, the enormous discrepancy between the results obtained by experiments with this salt in pure solution and the limit determined by field survey is completely obliterated. For in alkali lands magnesium sulphate is rarely, if ever, found in any quantity except in the presence of calcium sulphate; and it is commonly accompanied by both sodium and calcium sulphate (the Billings, Mont., type of alkali soil). Addition of sodium sulphate, which is itself so injurious in a pure solution, raises the limit for magnesium sulphate three times, while the presence of calcium sulphate allows a small proportion of the roots to barely survive during twenty-four hours in a solution of magnesium sulphate 480 times as concentrated as that which, in pure solution, represents the limit of endurance. A careful comparison was made between 0.3 and 0.4 normal solutions of magnesium sulphate, both in the absence and the presence of an excess of calcium sulphate, five individuals of *Lupinus albus* being cultivated for forty-eight hours in each of the four solutions.

The following table gives the results:

Magnesium sulphate with and without calcium sulphate.

Solutions.	Average elongation of the marked portion of the root.	General condition of the roots.
	Millimeters.	
Magnesium sulphate (0.3 normal)	0.7	Extremely flaccid and discolored with brownish blotches; extremely plasmolyzed.
Magnesium sulphate (0.3 normal)+calcium sulphate.	10.2	Turgor normal; plasmolysis none; but all roots quite badly discolored.
Magnesium sulphate (0.4 normal)	.3	About as in 0.3 normal
Magnesium sulphate (0.4 normal)+calcium sulphate.	13.0	Turgor normal; plasmolysis none; all but one root quite badly discolored.

The superior efficacy of cations over anions in neutralizing the toxic effect of other cations is illustrated by the discovery that sodium is equally effective as an antidote to magnesium chloride, whether it be added as sulphate (Na_2SO_4) or as chloride (NaCl).[a] A much more striking illustration is afforded by the fact that calcium, when added to a solution of magnesium sulphate or of sodium sulphate, is very much more efficacious when furnished as the relatively insoluble sulphate than as the readily soluble chloride. In other words, the presence of chlorine anions actually hinders the full exertion of the physiological effect of calcium cations, unless we are to believe that the superior efficacy of calcium sulphate is due merely to its greater influence in retarding the dissociation of the sulphates of magnesium and of sodium.

If we turn now to the effect of mixtures in which two kinds of cations are present we find that these are almost invariably much less poisonous than is the pure solution of the more toxic salt. Even the addition of a sodium salt (sulphate or chloride) to one of magnesium (sulphate or chloride) raises the limit of endurance for the latter three to six times. Still more remarkable is the effect of magnesium carbonate as an antidote to salts of sodium (carbonate, sulphate, chloride), raising their limits two to four times. But these effects are trivial as compared with the extraordinary efficacy of calcium in counteracting the toxic effects of other bases (magnesium, sodium).

Even when added as the but slightly soluble carbonate, calcium raises the limit of magnesium sulphate and of magnesium chloride sixteen times, of sodium sulphate more than five times, and of sodium chloride three times. Calcium chloride mixed with an equal volume of a magnesium or a sodium salt raises the limit of the latter as follows: Magnesium sulphate, one hundred and sixty times; magnesium chloride, forty times; sodium carbonate, fifty times; sodium sulphate, twenty-seven times, and sodium chloride, ten times.

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[a] On the other hand, sodium chloride is twice as effective as sodium sulphate in neutralizing magnesium sulphate.

The most effective of the calcium salts tried was, however, calcium sulphate. This, when added alone in solid excess, increases the maxima of concentration endurable by the roots as follows: Magnesium sulphate, four hundred and eighty times; magnesium chloride, eighty times; sodium carbonate, six times; sodium sulphate, sixty-six times, and sodium chloride, ten times.

Similar results have been obtained for magnesium chloride, sodium carbonate, sodium sulphate, sodium chloride, and calcium chloride in mixture.

It was further demonstrated by Kearney and Cameron that in the case of certain salts, when plant roots are exposed to pure solutions which are much too dilute to produce any toxic effect, there occurred a decidedly stimulating effect upon growth, as compared with that in the distilled-water control during a corresponding period. As would be expected, this was shown to be the case for salts of calcium, both the chloride and the sulphate acting as stimuli. Here, however, we have to do with salts which contain valuable elements of plant food.

But a marked stimulating action occurs in pure solutions of sodium carbonate (slight in 0.002 normal, marked in 0.00125 normal, and of sodium bicarbonate 0.01 normal). The most pronounced effect was obtained in a 0.00125 normal solution of sodium carbonate, the average elongation of the roots in that solution being one and one-half times as great as in distilled water during the same period. In the case of the two carbonates of sodium it seems necessary to regard the effect as one of chemical stimulus, pure and simple. That this is not due to the sodium ions is evident from the fact that very dilute solutions of other sodium salts (sulphate, chloride) gave purely negative results. It was at first thought that the physiological effects of sodium carbonate (Na_2CO_3) were attributable to the presence of hydroxyl ions in the solution, since the corrosive, clearing action of more concentrated solutions of this salt is precisely similar to that produced by potassium hydrate and sodium hydrate. But toxic as well as stimulating reactions of exactly the same character were obtained with solutions of the bicarbonate ($NaHCO_3$), in which a large excess of carbon dioxide was dissolved, and which gave no reaction with phenolphthalein, even at the end of the experiment.[a] In this case the consideration of free hydroxyl ions must be excluded. Hence the conclusion seems unavoidable that the carbonic acid (HCO_3) ions produce the stimulating effect, improbable as this would appear. To what agency should be ascribed the characteristic toxic action (so different in kind from that of sodium sulphate and sodium chloride) of stronger solutions of sodium bicarbonate, in which no free hydroxyl could be detected, is a question to which no answer can at present be given.[a]

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[a] Solutions of sodium carbonate which were many times too dilute to produce a stimulating effect, yet gave a strong reaction with phenolphthalein.

None of the other salts with which experiments were made in pure solution were shown to stimulate elongation of the roots, although the possibility is not excluded that solutions still more dilute than those employed will give positive results. Magnesium sulphate was found to be indifferent (neither toxic nor stimulating) at 0.0003125 normal, magnesium chloride at 0.000625 normal, sodium sulphate (nearly) at 0.002 normal, and sodium chloride[b] (approximately) at 0.005 normal.

These observations accord with the well-known principle that many violent poisons, if given in sufficiently minute doses, serve as beneficial stimuli. Familiar examples are the action of arsenic, mercury, strychnine, digitaline, etc., upon animals. Numerous investigators have obtained similar effects with plants by supplying them with very small quantities of various substances which can not be regarded as sources of plant food, such as the extremely toxic salts of some of the heavy metals. In practically all such cases, however, it is very probable that considerable hydrolysis had taken place and that the stimulation might well be attributed to the hydroxyl ions thus introduced into the solution.

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[a] In experiments with sodium carbonate and sodium bicarbonate as to their effect upon animals, Loeb encountered a very similar anomaly. The stimulating effect of various hydrates upon the absorption of water by a muscle immersed in a sodium chloride solution was shown to be clearly due to the hydroxyl ions, being equal in amount when equivalent solutions of hydrates were used, irrespective of the character of the basic ions [see Pflüger's Archiv, 69, 10 (1898)]. The similar effect produced by carbonates of sodium and potassium was ascribed to the same factor, the hydroxyl ions (l. c., p. 20). On the other hand, the effect of sodium carbonate (Na_2CO_3) in stimulating skeleton formation in the pluteus of a sea urchin appears to be due to the carbonic acid (HCO_3) ions, since sodium in other forms, as well as hydroxyl in the form of potassium hydrate, gave negative results [Am. Journ. Physiology, 443 (1900)].

[b] Pfeffer [Pflanzenphysiologie, ed. 2, 1, 425] observes that possibly chlorides (e. g., sodium chloride), like so many other substances, act in dilute solutions as chemical stimuli. Storp [Biedermann's Centralbl., 13, 76 (1884)] obtained a stimulating effect upon the germination of seeds by immersing them in a 0.01 per cent solution of sodium chloride. Jarius [Landw. Vers.-Stat., **32**, 149 (1886)] found that even a 0.4 per cent solution of sodium chloride stimulated the germination of seeds of wheat, rye, rape, maize, beans, and vetches. Jones and Orton (Bul. Vermont Agr. Exp. Station No. 56, p. 12) observed, as a consequence of the application of sodium chloride to land in order to exterminate the weed known as orange hawkweed (*Hieracium aurantiacum*), a marked stimulating effect upon the growth of grass in the same field. Peligot [Comptes rendus, **73**, 1078 (1871)] suggests that the stimulating effect upon field crops which is sometimes obtained with sodium chloride may be due to its facilitating the decomposition of calcium phosphate and thus increasing the amount of phosphoric acid at the disposal of the plant. Kellner [Landw. Vers.-Stat., **32**, 365 (1886)] attributes to a similar liberation of phosphoric acid the stimulating effects of iron sulphate upon plant growth recorded by Koenig and by Griffiths. Réveil [De l'action des poisons sur les plantes, p. 41 (1865)] found that sodium hypochlorite in a solution of 0.1 per cent stimulates germination and growth, but is injurious, especially to herbaceous plants, when applied in greater concentration.

The effect of acids and of salts upon the seedlings of Indian corn (*Zea mais*), wheat (*Triticum vulgaris*), and clover (*Trifolium pratense*) have been investigated by Cameron and Breazeale.[a] The following table gives the toxic limits for seedlings in acid solutions:

Toxic limits for seedlings in acid solutions.

Solution.	Number of liters per gram at toxic limits for—		
	Corn.	Wheat.	Clover.
Hydrogen sulphate	3,000	15,000	20,000
Hydrogen chloride	3,000	18,000	20,000
Hydrogen nitrate	2,250	15,000	20,000
Hydrogen acetate	850	20,000	20,000
Hydrogen oxalate	1,750	15,000	20,000
Hydrogen succinate	600	20,000	20,000
Hydrogen malate	1,250	20,000	20,000

In the case of clover the uniformity of the figures for the limits in acid solutions is striking and seems to indicate that the toxic action was due to the hydrogen ion alone, for it must be assumed that with a dilution N/20,000 practically complete dissociation exists for each and every one of the acids. But the results obtained with wheat seedlings are not in accord with this view, since the dilutions were also such as to insure complete dissociation, although quite different concentrations of the several acids gave the toxic limits. With the corn seedlings in acid solutions the results are quite as difficult to interpret. They can not be regarded as due to this effect of the hydrogen ion alone, as the concentration with respect to this substance in the solutions representing the toxic limits varies considerably.

In the following tables are given results obtained in solutions of acids when in addition to the free acid H the indicated amounts of a corresponding potassium or calcium salt, respectively, were also present:

Toxic limits for seedlings in solutions of acids containing various amounts of the corresponding potassium salts.

Plant.	Solution.	Number of liters per gram at toxic limits with respect to free acid in solutions containing—		
		No potassium.	N/100 potassium.	N/50 potassium.
Corn	Sulphuric acid	3,000	2,100	1,750
	Hydrochloric acid	3,000	2,500	1,750
	Nitric acid	2,250	2,100	1,750
	Acetic acid	850	700	500
	Oxalic acid	1,750	1,000	800
	Succinic acid	600	75	60
	Malic acid	1,250	750	125
Wheat	Sulphuric acid	15,000	8,000	7,000
	Hydrochloric acid	18,000	8,250	7,250
	Nitric acid	15,000	7,750	7,000

[a] Jour. Phys. Chem., 8, 1 (1904).

Toxic limits for seedlings in solutions of acids containing various amounts of corresponding calcium salts.

Plant.	Solution.	Number of liters per gram at toxic limits with respect to free acid in solutions containing—			
		No calcium.	N/100 calcium.	N/50 calcium.	Saturated with calcium.
Corn	Sulphuric acid	3,000	950	700	400
	Hydrochloric acid	3,000	1,750	1,200	
	Nitric acid	2,250	1,500	1,000	
	Acetic acid	850	500	400	
	Oxalic acid	1,750			1,500
	Succinic acid	600	35	20	10
	Malic acid	1,250	200	100	100
Wheat	Sulphuric acid	15,000	3,250	2,250	
	Hydrochloric acid	18,000	3,250	2,750	
	Nitric acid	15,000	3,000	2,000	
Clover	Sulphuric acid	20,000	3,250	1,750	1,700
	Hydrochloric acid	20,000	4,000	2,750	
	Nitric acid	20,000	3,500	1,750	
	Oxalic acid	20,000			15,000

In a recent paper,[a] Breazeale has determined the concentration of a nutrient solution which is best adapted to the growth of wheat. The nutrient solution contained chemically equivalent amounts of calcium sulphate, magnesium phosphate, potassium carbonate, sodium nitrate, and ammonium chloride. To solutions containing 10, 70, 150, 745, and 1,545 parts per million, respectively, ferric chloride was added in such quantity as to give a solution containing 5 parts per million of this salt. After fifteen days the average transpiration of over 200 plants was as follows:

Average transpiration of 200 wheat plants growing in solutions of different concentrations.

Solution concentration.	Relative transpiration.
P. p. m.	
15	100
75	161.6
155	188.7
750	163.3
1,550	131.9

The concentration which gives the maximum in transpiration is about 300 parts per million of total solids. The effect of adding relatively large quantities of one of the constituents of the nutrient solution is given in the following table. The time of the experiment was thirteen days.

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[a] Science, N. S. **22**, 146 (1905).

Average transpiration of 60 wheat plants growing in solutions of different concentrations.

Medium.	Relative transpirations for period of experiment.
Nutrient solution, 15 parts per million	100.0
Same+140 parts per million $CaSO_4$	205.5
Same+140 parts per million $MgHPO_4$	143.5
Same+140 parts per million K_2CO_3	224.4
Same+140 parts per million $NaNO_3$	156.3
Same+140 parts per million of four above salts in chemical equivalent amounts	241.9
Nutrient solution 15 parts per million	100.0
Same+60 parts per million $CaSO_4$	117.8
Same+140 parts per million $CaSO_4$	157.7
Same+735 parts per million $CaSO_4$	188.9
Same+1,535 parts per million $CaSO_4$	155.5
Nutrient solution, 15 parts per million	100.0
Same+60 parts per million NaCl	111.1
Same+140 parts per million NaCl	114.9
Same+735 parts per million NaCl	117.2
Same+1,535 parts per million NaCl	95.4

Sodium chloride, which furnishes none of the elements usually classified as plant-food materials, was also used to increase the concentration of the original solution. Sixty plants were used in this case, being grown for fifteen days. The treatment was the same as that with calcium sulphate just described, and the results showed the same general effect, although the actual differences between the different cultures were not nearly as great. The last fact is probably due to the toxic effect of the chlorine ion, tending to retard growth and thus partially masking the effect of concentration.

RESISTANCE OF PLANTS TO BLACK ALKALI.

In a paper by Cameron upon the Resistance to Black Alkali by Certain Plants[a] it has been shown that certain plant species can make a satisfactory growth on soils containing relatively large amounts of soluble carbonates. The plants *Distichlis spicata*, *Suæda intermedia*, and *Atriplex bracteosa* have been shown to exude considerable amounts of soluble organic acids, which tend to reduce the alkalinity in the immediate neighborhood of the plant and especially about the root crowns, where corrosion by black alkali has been so frequently observed.

From all these experiments it is apparent that the toxicity of any salt in solution is greatly modified by the presence of other salts, and that the toxic effect is by no means the same as the toxic effect of the several constituents. For instance, a solution containing 7 parts per 100,000 of magnesium sulphate or a solution containing 53 parts per 100,000 of sodium sulphate will kill seedlings of white lupine. With a solution of the two salts, however, containing 21 parts of magnesium sulphate and 80 parts of sodium sulphate it is just toxic to these seedlings. Such cases might be multiplied. The effect of one kind of ion in counteracting the physiological action of another kind can not be entirely explained by a study of the chemistry of the solution itself, but must in part be referred to complicated changes in the protoplasm of the organisms. The theory that ions furnished by the dissociation of electrolytes form intimate combinations with the proteids of protoplasm, and that their mutually antagonistic effect expresses itself in a replacement of one kind of ion by another as a result of change in the composition of the surrounding solution, would appear to afford the key to this problem.

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[a] Report No. 71, U. S. Dept. Agr. (1902), p. 71.

FORMATION OF ALKALI BY PLANTS.

The great value of saltbushes for certain soil conditions and for certain kinds of cattle feeding seems to be well established, but there is an element of danger, expressed in the prevalent belief that most of these indigenous plants convert the less harmful neutral salts, such as sodium chloride and sodium sulphate, into alkali carbonates—that is to say, the less harmful "white alkali" is converted into the more noxious "black alkali," as has been shown by the presence of sodium carbonate immediately under such plants, whereas no trace of it exists some distance away. It may be possible that the plants with their enormous root systems actually gather up minute traces of sodium carbonate, which may be present in lower depths of soil, gradually causing an accumulation at the surface on the decay of their roots and branches. But the generally accepted hypothesis of the conversion of the neutral salts appears more probable.

A specimen of the creosote bush (*Covillea tridentata*) was examined. This, while a desert plant, is said to shun soils where there is much water-soluble salts, and that its presence can be taken as a sure indication of land free from injurious quantities of alkali. It is found in dry, well-drained upland soils.

The aqueous extract of the dried leaves failed to show the presence of any sodium carbonate or sodium chloride, although it was slightly acid. It would appear that the chlorine and sodium, which are found on analysis of the ash, are in organic combination and that the salts are formed in the process of ashing the plant. From an analysis of different parts of the plant Cameron[a] has found that the amount of chlorine in the leaves is nearly three times that found in the stems. Thus the chlorine present is probably being concentrated in the leaves and is in organic combination.

From the results of the analysis of greasewood (*Sarcobatus vermiculatus*), before and after ashing, it appears that the plant contains all its chlorine as soluble chlorides, while the carbonate of sodium, which composes over one-half of the ash of the leaves and blossoms, is formed in the process of ashing.

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[a] Report No. 71, U. S. Dept. Agr., p. 64.

A striking feature is the much larger amount of ash from the leaves and blossoms than from the stems and the markedly larger percentage of the alkali salts in the ash of the former. The idea suggests itself that possibly this plant takes up and stores the salts and holds them as such until it is ready to use such part of them as it needs. On the other hand, it may be that these salts are present only because the plants can not prevent their accumulation, and, so far from being an inherent feature of the plant's economy, it may be a most undesirable accident due to their peculiar environment, but an accident in spite of which these particular plants are able to survive. But, as Schimper[a] has pointed out, this can not be true in all cases, as evidenced by the fact that halophilous plants show a tendency to take up more salts than nonhalophilous species, even when grown in nonsaline soils.

It is evident that in the decay of wood or leaves or, in general, of plant tissues alkaline carbonates are furnished to the soil. It may be that the process of decay will furnish at the same time organic acids stronger than carbonic acid and in sufficient quantity to combine with all the bases and prevent an alkaline reaction. In humid regions the alkali thus formed is removed by leaching or similar processes and by chemical reactions with the other soil components, for which reactions water is necessary.

RECLAMATION OF ALKALI LANDS.

The first question naturally arising in considering the reclamation of alkali lands is: Are the lands productive after their reclamation has been accomplished? Of this there can be no question, since they are rendered unfit for cultivation only because of the excess of certain soluble salts they contain. It has long been pointed out that a slight quantity of these salts even stimulates crops, and it is only when they accumulate in large quantities that the lands cease to be of value for agricultural purposes. In countries of abundant rainfall the application of common salts upon the lands has been practiced perhaps for centuries. In southeastern Europe it is customary in some districts to scrape up the surface accumulations of alkali and apply them to lands where no such accumulations occur, and the expression is common that salt is the life of the soil. Moreover, there are many examples of the great productiveness of reclaimed alkali land, not only in the arid regions of the United States, but in India and northern Africa as well.

This leads, then, to the question: Is the reclamation of alkali lands practical—that is, does it pay to reclaim such lands? The cost of reclaiming alkali lands depends on many factors, and in considering any system of reclamation the value of the land after it has been reclaimed must be taken into account. In new and partially developed districts where excellent virgin soil can be purchased for a few dollars an acre it is obvious that it would not be feasible to expend much time or money on reclaiming alkali lands. So rapid has been the development in the West, however, that the localities where fine land can be purchased at such prices are fast becoming the rare exception. In by far the greater part of the irrigated West land values have advanced so rapidly that seldom are good lands to be had at less than from $30 to $50 an acre, while in the older and better developed regions good lands frequently find ready sale at several hundred dollars an acre. In many of the older irrigated districts, moreover, the acreage of good lands is limited, and with the fancy prices which good soils command the rancher can well turn his attention to the reclamation of alkali lands, though this may prove somewhat expensive. The extent of land damaged by alkali has already been mentioned as being, according to conservative estimates, one-tenth of the entire area of irrigated land in the western part of the United States, or 847,000 acres. When we realize that this area is yearly increasing, the importance of reclaiming such lands is strongly emphasized.

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[a] Schimper, Pflanzengeographie, p. 101 (1898).

METHODS USED IN RECLAIMING ALKALI LANDS.

Among the most prominent methods proposed for reclaiming alkali lands may be mentioned the removal of the crust by scraping, the application of chemical correctives, the growing of alkali-resistant crops, flooding and then drawing off the water, and repeated flooding combined with underdrainage.

SCRAPING THE SURFACE.

The removal of alkali salts by scraping the surface calls for much labor and must in most cases be constantly repeated, any good that may result being merely temporary. In case the greater part of the alkali has accumulated at the surface and the deep subsoil contains little or no alkali, permanent good may result from this method, since by the removal of the alkali from the surface crops may be grown, and by subsequent cultivation or by keeping the surface shaded evaporation and the attending accumulation of alkali may be reduced to a minimum. The cases where large surface accumulations of alkali occur with none in the subsoil are rare, however, and this method of reclamation probably has not a wide application.

APPLYING CHEMICAL CORRECTIVES.

The second method of treating lands has been widely advocated and practiced for many years, especially in California. In some cases permanent benefit results from this method of reclamation. It has been long emphasized that the application of gypsum to land containing black alkali (sodium carbonate) results in changing the extremely injurious black alkali to white alkali, which is not as harmful to plant growth. The following chemical reaction takes place:

$$Na_2CO_3 + CaSO_4 \rightleftarrows CaCO_3 + Na_2SO_4,$$

the sodium carbonate being to a greater or less extent converted to less harmful sodium sulphate and the harmless and but slightly soluble carbonate of lime. To bring about this result, it is necessary that the soil should be well drained and aerated. This method of treatment of black alkali was first suggested by Hilgard many years ago. To test the efficiency of this treatment, experiments were conducted on a piece of land near Tulare Lake on soil strongly impregnated with black alkali. For many years gypsum has been applied to the soil with varying degrees of success. Much of the land was benefited, but other parts of the tract did not respond as quickly as hoped for, and the land was still being treated as late as 1904.

In the Yearbook[a] for 1895 Hilgard speaks of the use of gypsum as follows:

> The amount required per acre will, of course, vary with the amount of salts in the soil, all the way from a few hundred pounds to several tons in the case of strong alkali spots; but it is not usually necessary to add the entire quantity at once, provided that sufficient be used to neutralize the alkali near the surface and enough time be allowed for the action to take place. In very wet soil this may occur within a few weeks; in merely damp soils, in the course of months; but usually the effect increases for years, as the salts rise from below.
>
> The effect of gypsum on black alkali land is often very striking, even to the eye. The blackish puddles and spots disappear, because the gypsum renders the dissolved humus insoluble and thus restores it to the soil. The latter soon loses its hard, puddled condition and crumbles and bulges into a loose mass into which water now soaks freely, bringing up the previously depressed spots to the general level of the land. On the surface thus changed seeds now germinate and grow without hindrance; and as the injury from alkali occurs at or near the surface, it is usually best to simply harrow in the plaster, leaving the water to carry it down in solution. It must not be forgotten that this beneficial change may go backward if the land thus treated is permitted to be swamped by irrigation water or otherwise.

On soils containing slight quantities of sodium carbonate with but small amounts of white alkali, this treatment is advisable, since the sodium sulphate resulting from the chemical reaction is one of the least harmful varieties of white alkali, and greater quantities of this material can be endured by growing crops. The gypsum is also of benefit in correcting the unfavorable physical condition caused by the black alkali and restoring the soil to a good condition of tilth. On soils containing any considerable quantities of sodium carbonate it is to be doubted if the application of gypsum is to be advised, since the treatment does not remove the alkali, but merely changes it to a less injurious form. Even after the chemical reaction has taken place there still may be present in the soil too much of the sulphate to grow crops with success. Again, it should be noted that this method does not remove the cause of the accumulation of the alkali, and it is frequently but a question of time until the white alkali itself will accumulate in sufficient quantities to be destructive of plant life. It should also be pointed out that this treatment is of no value on lands other than those carrying sodium carbonate. No chemical treatment can at present be recommended on lands containing either chlorides or sulphates, and as many districts contain the one or the other of these as the predominating salt, this method of reclamation is of limited application. The use of gypsum as a corrective of black alkali has never been strongly recommended by this Bureau, since it is believed that other methods of reclamation are more permanent, and, all conditions considered, are more economical.

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[a] Yearbook of the Department of Agriculture, 1895, Origin, Value, and Reclamation of Alkali Lands, E. W. Hilgard.

GROWING ALKALI-RESISTANT PLANTS.

Concerning the third method of reclaiming alkali lands much has been written by the various experiment stations in the Western States. The utilization of such lands and the gradual removal of the excess of alkali salts has been attempted with partial success by the growing of certain alkali-resisting plants of more or less economical value. The harvesting of the crop in the case of such plants removes a considerable amount of the alkali salts which have been taken into the plant tissues and cells. This method is successful only to a limited extent, and it likewise fails to remove the cause. For the strongest alkali soils the wild saltbushes, salt grass, and Australian saltbush are available. Such lands can only be used as pastures. Lands less strongly impregnated will frequently grow sorghum or sugar beets, which can withstand considerable alkali. The growth of such plants alone is a slow and uncertain method of reclamation, but under certain conditions this method may be used to derive some income from lands at present having little or no agricultural value.

FLOODING AND DRAWING OFF THE WATER.

In many districts it is a common practice to build small dikes around a field containing alkali. The field is then flooded, the water allowed to remain for a short time, and then the banks are cut and the water drawn off. The principle is to dissolve the surface coating of salt and flood it off. Jensen, in the report of the Yakima area in Washington, states that this method is practiced in the Atanum Valley. In speaking of the efficiency of the method, Jensen writes as follows:

> This is an excellent method for filling up the soil completely with alkaline water and for the accumulation of more alkali by evaporation. Not only is the subsoil water under the

particular area itself raised, but also under other lands lying below it. This is the very way the alkali in this area originated, and no better method could be devised for making the general conditions of the area worse than they already are. A series of such dikes and the surrounding soil seen in June (1901) resembled snowdrifts, the white material being heavy accumulations of alkaline carbonates.

As Hilgard years ago pointed out, the reason this method avails nothing is that at the first wetting of the soil the dissolved salts immediately sink into the soil, and the water standing on the soil remains almost unchanged. There are some cases, however, where this method may be productive of good results.

APPLICATION OF MANURE.

Another method of treating alkali land is the application of manure. In itself the manure has but little, if any, power to change the chemical composition of the alkali. It may, however, as Tinsley[a] suggests, be the means of putting the soil in better physical condition, so that it will permit irrigation water more readily to permeate it, thereby washing the alkali below the surface and permitting shallow-rooted crops to make a growth. It may also stimulate the growth and vigor of young plants, and in this manner enable them better to withstand the injurious effects of alkali. The general result from this method of treatment in most cases is negative and need receive no further consideration.

TREATMENT OF ALKALI SOILS IN EGYPT.

In Egypt the reclamation of alkali lands has received a great deal of attention for many years. In 1902 Means made a study of the alkali conditions and the different methods of reclamation in use. The following summary is taken from Bulletin 21 of this Bureau, in which Means described the results of his studies. He found three methods of reclamation in use, each of which was successful under the conditions appropriate for its use.

Colmatage or warping.—This method of reclamation consists simply in flooding land with muddy water long enough to allow the mud to settle, after which the clear water is drawn off and more muddy water run on. Very little attention is paid to drainage, except in so far as surface drains are dug to carry away the clear water. The popular impression prevails that by this method the alkali or salt is covered up with sufficient good soil to permit plant roots to thrive. As a matter of fact, the efficiency of the method depends much more on the fact that the alkali is washed down into and mixed with the subsoil, so that its concentration at the surface is diminished. The total amount of alkali in the soil is very slightly reduced, and when conditions again become favorable for the rise of the alkali it returns to the surface and proves as troublesome as before. Where, however, the depth of soil and subsoil above standing water is great, and where rice or other wet-land crops are to be grown, colmatage may advantageously be used for reclamation. Large quantities of water are required and much land is made swampy. As an efficient and permanent remedy for alkali land this method can not be recommended for general use.

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[a] Alkali. By J. D. Tinsley. Bul. No. 40, N. Mex. Expt. Sta.

Flooding with open drains.—This is the method in common use in Egypt. The land is thoroughly leveled, open ditches to a depth of 32 inches are dug at intervals of 150 to 450 feet, and the land is banked up and flooded to a depth of 4 inches until sufficiently leached of alkali or salt to permit plant growth. This method is thoroughly effective for the removal of salt, but it has the objectionable feature of open ditches.

Flooding with tile drains.—This method has only been tried experimentally in Egypt, but promises to be the most rapid and effective way of reclaiming the land. Tile drains are placed 30 inches deep and 35 feet apart, at a cost of $30 per acre.

FLOODING AND UNDERDRAINAGE.

In principle this method is exceedingly simple. The accumulations of alkali are easily soluble in water, and if sufficient water is applied to the surface it will soak through the soil and carry with it the dissolved alkali, thus freeing the soil from such harmful accumulations. Repeated flooding will eventually leach all of the alkali from the soil, provided the underdrainage permits the water to pass readily through the soil. It has long been the custom of the Pima Indians in the Salt River Valley, Arizona, to take up the alkali lands that were irrigated in prehistoric times. By diverting the water from the Salt River through small ditches they heavily flooded the lands, washing the alkali into the deep porous subsoil, where it drained away with the country drainage. In this manner the lands were sufficiently reclaimed to permit cultivation of even the most sensitive crops. This is perhaps the first known example of successful alkali reclamation in this country.

As a result of the detailed study of the soil and alkali condition in the various parts of the arid West, the Bureau soon was convinced of the feasibility of reclaiming alkali lands by flooding after some system of drainage had been installed. Notwithstanding the recommendations in the various reports of the areas studied that drainage is a practicable, safe, and sure means of permanently reclaiming alkali lands, no steps had been taken by persons most deeply interested to check or remove the evil. The Bureau, after careful consideration, decided that the most convincing way of bringing the truth of its recommendations and the value of drainage in reclamation work before the people was to demonstrate it by the actual reclamation of some of the alkali land.

RECLAMATION EXPERIMENTS CARRIED ON BY THE BUREAU OF SOILS.

SALT LAKE CITY TRACT, UTAH.

In the year 1902 a tract of 40 acres was selected west of Salt Lake City, Utah, and steps taken to reclaim the land. During the period of 1902–1904 the work was carried on under the direction of W. H. Heileman, assisted by Rudolph Boss. In the following pages the history of the reclamation work is given from 1902 to the close of the farming season of 1905. Circular No. 12, published in 1903 by this Bureau, discusses the installation of the drainage system. The following statements consist of excerpts from that circular, together with a discussion of the results accomplished since its publication.

In 1899 a party from the Bureau of Soils, in cooperation with the Utah Experiment Station, made a soil survey[a] of that portion of the Salt Lake Valley lying west of the Jordan River. In this report full and careful consideration was given to the question of the alkali soils around Salt Lake City, the cause of their formation, their character and present extent, and the means of their amelioration and reclamation. The following paragraphs are taken from this report:

> On the west side of the Jordan River the earliest attempts at irrigation were on the Jordan meadows, or river bottom lands, the water supply being obtained from the Jordan River by means of small canals. Subsequently the Brighton and North Point and the North Jordan canals were run upon the first terrace above the river, and following these were the South Jordan and the Utah and Salt Lake canals on the second and third benches, respectively.
>
> As is frequently the case, the irrigation on the benches caused an accumulation of seepage and alkali on the river bottom land, so that much of it has been abandoned. The largest and most seriously damaged area, however, is just south of Twelfth street road, and comprises a strip of land varying from half a mile to a mile and a half in width, and extending 10 miles west from the river. Here the seepage and surplus waters from the outer extremities of the Utah and Salt Lake, the South Jordan, and the North Jordan canals have collected to an alarming extent. Indeed, the damage has gone so far that a chain of lakes has formed, presenting a water surface of fully 1,000 acres. The area affected is not less than 10 square miles.
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> The seepage and waste waters from the canals account in great measure for the 10 square miles of good land which has already been ruined by seepage and alkali. It has been shown that the water is of good quality, and the lands of the upper benches are naturally free from any great excess of alkali; but the continual seepage from the canals during the growing season for a great many years has transported a quantity of salt to the lower levels.

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[a] A Soil Survey in Salt Lake Valley, Utah, by Frank D. Gardner and John Stewart. Field Operations, Division of Soils, 1899, pp. 77–114. This report was also published as Bul. 72 of the Utah Experiment Station.

The necessity of careful construction of the canals, especially those on gravelly lands, and the desirability of preventing the waste water from flowing over the lower levels is sufficiently obvious without further comment.

The application of water on the lowlands west of Salt Lake City, where there is a large amount of alkali in the lower depths, has been attended with very disastrous results to crops. The salt has quickly risen to the surface and, even where the surface foot was originally free from alkali, the crops have been completely ruined in the course of two or three years.

* * * * * * *

Attention has already been called to the necessity of underdrainage for protection against injury from seepage waters and alkali and for the reclamation of injured lands. Irrigated lands in the Salt Lake Valley are worth at least from $60 to $100 per acre. Land immediately adjacent to Salt Lake City, especially if held as surburban property and if free from alkali, would be worth much more than this. There is plenty of good tile clay in the vicinity of Salt Lake City, and tile could be manufactured for the farmer at a reasonable cost. It is estimated that it would cost from $10 to $20 an acre to underdrain these lands, which under the present conditions have a merely nominal value.

During the course of this investigation particular attention was given to the possibility of reclaiming the vast tract of 125 square miles between Salt Lake City and the Great Salt Lake. The levels of the railroad surveys and of the canal companies were freely consulted. At Salt Lake City the level of the Jordan River is about 20 feet above the level of the water in the Great Salt Lake. The distance across is about 14 miles. There is a slight ridge, however, running a little west of north about a third of the way across from Salt Lake City. From the crest of this ridge to the Great Salt Lake there is a uniform fall of approximately 3 feet to the mile. This would be ample for the main drainage canals, as the irrigating canals have only about one-half this fall. Furthermore, there are many draws, already 4 to 8 feet deep, extending like fingers through this area, which with little additional work could be made to answer for a considerable part of the drainage system.

On account of the impervious nature of the Jordan clay, the great salt content, and the low elevation it would not be advisable to attempt drainage over this class of land at the present time. Subtracting this area, estimated at 35 square miles, from the 125 square miles, the value of the remaining lands, if thoroughly drained, would be about $3,000,000. At present they have merely a nominal value.

Since the publication of this report no step has been taken by State or county authorities toward any general scheme of drainage and reclamation, and so far as the knowledge of the Bureau goes no work of any moment has been attempted by individuals.

In order to bring a matter of so much importance to the attention of the farmers, as well as of the community at large, an experiment to demonstrate the value of drainage in alkali reclamation was planned by the Bureau of Soils. In the carrying out of the work the Utah Experiment Station entered into cooperation with the Bureau of Soils, and in 1902 a tract of 40 acres, belonging to Mr. E. D. Swan, was selected for the demonstration. This tract lies 4 miles west of Salt Lake City, in sec. 5, T. 1 N., R. 1 E.

The land, at the time work was commenced, was all strongly impregnated with alkali salts, and had nothing growing upon it except a few alkali weeds, the most prominent of which was greasewood (*Sarcobatus vermiculatus*). The land was considered valueless by the farmers of the neighborhood.

The tract lies on the east side of Williams Lake, and at its highest point has an elevation of about 8 feet above the part of the lake bed adjacent to the tract.

The cost of this installation was as follows:

270 feet 10-inch tile, at $100 per M feet	$27.00
300 feet 8-inch tile, at $64 per M feet	19.20
520 feet 6-inch tile, at $27.50 per M feet	14.30
6,580 feet 4-inch tile, at $17 per M feet	111.86
2,890 feet 3-inch tile, at $13 per M feet	37.57
Fittings	2.80
Freight on 3 carloads, Ogden to Buenavista	60.00
Cartage and scattering tile	17.50
606 rods ditch, at 50 cents per rod	303.00
67 rods main ditch, at 54 cents per rod	36.30
673 rods covering with team	19.50
150 feet outlet ditch (open)	6.00
One-fifth cost of tools	5.00
Total cost	660.03

The average cost of the drainage system completed was $16.50 per acre, and it is believed that the drainage of larger tracts could be accomplished at about the same cost.

The tract is composed of a surface soil of a silty loam and sandy loam, with a depth ranging from 12 to 18 inches. The underlying material is a heavy clay. A very shallow sand stratum occurs at a depth of 4 feet over the greater part of the tract. The lower or lakeward half of the tract is underlain at an average depth of 26 inches by white calcareous hardpan from 1 to 2 inches in thickness.

With the above soil and hardpan conditions it was deemed advisable to place the drains 150 feet apart, and this interval was used, except in one instance. The systems for the 40 acres includes eight lateral drains and one main drain. Each of the laterals is 1,250 feet long, and is laid with 850 feet of 4-inch and 400 feet of 3-inch draintile. The exception already referred to is in the interval for lateral No. 8, which is laid 200 feet from the nearest lateral, the object being to study its efficiency under such conditions of soil as exist in this tract.

The main drain is put in across the lower part of the tract, 20 feet from its west side, and is met by seven of the laterals. This drain was laid with 270 feet of 10-inch, 300 feet of 8-inch, and 520 feet of 6-inch tile.

Over the greater part of the tract the drains were laid at a depth of 4 feet. The drains were laid on a grade of not less than one-tenth foot in 100 feet, except where 3-inch tile was used, when the grade was somewhat higher. Flooding has been carried on systematically, the land being divided into checks and plats by levees and each plat treated in rotation. During each flooding water has been added to an average depth of 4 inches. The movement of the water into the soil has been regular and, considering the character of the clay subsoil, rapid, and the drains have quickly filled after the floodings and have run freely throughout the experiment.

After the installation of drains under the land in question, a partial leveling of the tract was undertaken. The tract represented virgin soil conditions and had a more or less uneven surface and was generally covered with greasewood. The grade of the land running diagonally from the intake weir to the outlet ditch was rather heavy, being about 8 feet between the intake weir and the bottom of Williams Lake. The Utah Experiment Station was to clear the land and level the surface. This was rather difficult and expensive, owing to the fact that the tract had at one time been plotted and had had streets graded upon it and a railroad embankment of some 4 feet in height and nearly a rod wide ran diagonally across the tract. After the land had been cleared, some leveling was done and the land divided into small plots or checks by means of levees.

The preparation of the land surface for flooding operations is an important step in the reclamation from alkali. With level land the task of preparing inclosures is comparatively easy, and large plots of land can be inclosed by a single low levee or ridge. Land of greater grade or slope, however, requires either that the land be inclosed in many levees, thus making small plots, or that, if a less number of levees be constructed, the land within each plot be leveled to practically the same elevation throughout. Too much attention can not be given to the initial preparation of the land, since uniform leaching from alkali can only be accomplished on lands well leveled or lands which can be flooded to a uniform depth during reclamation.

During the season of 1903 the land was flooded once each week, with occasional longer intervals when the supply canal was being repaired or during times when the land was being plowed or the levees repaired.

Before any water was applied to the tract a detailed survey was made to determine the alkali content of the soil. This initial survey was made in September, 1902. The land was then flooded once and allowed to remain until the next spring.

In May, 1903, before work was commenced, a second survey was made; and a third survey of the tract was made in October, 1903, after the close of the season's operations.

The following table shows the volume of water added to the tract from September, 1902, until October, 1903. The table shows also the volume of drainage over the outlet weir, and the salts (alkali) removed from the tract in the drainage water. The results are obtained from continuous measurements and daily collections of water samples for the entire period.

Total quantity of water used in flooding the tract, quantity flowing off through drains, and quantity of salts removed in drainage water.

Month.	Volume of water added to tract.	Volume of drainage water from tract.	Salts in drainage water.
	Cubic feet.	*Cubic feet.*	*Pounds.*
1902—September	284,400	158,700	152,200
October	940,000	265,000	195,100
November	[a]171,300	251,000	353,800
December	[a]166,500	139,700	187,800
1903—January	[a]291,800	257,300	391,200
February	[a]136,400	174,400	214,800
March	[a]132,000	428,000	590,700
April	[a]112,000	26,900	26,500
May	[a]576,900 760,900	521,500	567,100
June	[a]106,000 676,500	274,500	345,200
July	[a]36,580 1,691,970	480,490	556,459
August	2,122,160	814,890	1,221,742
September	2,352,920	1,195,976	1,654,115
October	351,290	663,420	840,981
Total	10,909,620	5,651,776	7,297,697

[a] Fell as rain or snow.

Total volume of canal water used	cubic feet	9,180,140
Volume falling as rain and snow	do	1,729,480
Total volume from above sources	do	10,909,620
Total water used	acre feet	250.4
Salts added in the canal water	pounds	900,000

The total volume of drainage was 5,651,776 cubic feet, or 51.8 per cent of the water added to the tract. This 51.8 per cent drainage water carried 3,648 tons of salts over the outlet weir. The remainder of the salts removed from the tract have passed into the deeper subsoil and been carried away by the natural subdrainage.

The above record shows the results obtained during 1903 up to October 31. During the season of 1904 the operations on the land were continued, and during that season a practical seed test was applied to the tract.

The following table shows the volume of water added between October 31, 1903, and October 1, 1904:

Total quantity of water used in flooding the tract, quantity flowing through the drains, and quantity of salts removed from October 31, 1903, to October 1, 1904.

Month.	Volume of water added to tract.	Volume of drainage from tract.	Salts in drainage water.
	Cubic feet.	*Cubic feet.*	*Pounds.*
1903—November	563,376	113,137	126,364
December	40,656	50,376	43,953
1904—January	217,800	26,396	18,912
February	299,112	382,628	475,631
March	187,308	380,114	521,974
April	255,552	258,519	382,335
May	382,974	60,903	61,466
June	44,970 618,172	68,132	31,487
July	87,120 1,610,807	430,459	385,364
August	35,820 1,920,726	774,285	711,021
September	20,320 802,153	579,215	579,215
Total	6,986,866	3,124,164	3,337,722

	Cubic feet.
Total volume canal water used October 31, 1903, to October 1, 1904	4,951,858
Volume falling as rain and snow	2,035,008
Total volume for above period, all sources	6,986,866

For the above period the total volume of drainage was 3,124,164 cubic feet. The volume of drainage was 44 per cent of the water added to the tract. This quantity of drainage water carried 1,669 tons of alkali salts over the outlet weir. The remainder of the water reaching the tract (56 per cent) was in part carried below the drains and in part lost through surface evaporation.

From the initial installation to October 1, 1904, we have the following:

Water added to November 1, 1903	cubic feet..	10,909,620
Water added from November 1, 1903, to October 1, 1904	do....	6,986,866
Total volume of water added	do....	17,896,486
	acre-feet..	410
Salts eliminated to November 1, 1903	tons..	3,648
Salts eliminated from November 1, 1903, to October 1, 1904	do....	1,669
Total tonnage of salts removed	do....	5,317

The initial tonnage of alkali in this tract in September, 1902, by a careful alkali survey, was 6,651 tons. From the above record it would seem that about all the alkali had been filtered from the tract to a depth of 4 feet. Especially does this seem true when we consider that this tonnage was obtained from little more than half of the water actually added to the tract. One factor, however, remains undetermined, viz, the volume of water lost by surface evaporation.

Certain phenomena enter into the work which tend to show that the salt removed over the outlet of the tract will finally exceed the actual tonnage originally present. We find the reclamation from alkali is limited to the 40 acres in question, but that the effect of this drainage system is far-reaching. Unmistakable evidences appear which show that the land lying contiguous to this tract has been most definitely acted upon in regard to its alkali content by the drains installed on the 40 acres. Lands lying above this tract which in years past have never produced crops have during the past season yielded almost normally. The drains near these lands have carried from them their underground water and the alkali which it contained.

The results obtained at the outlet weir show an unmistakable movement of alkali, and the changes which have taken place in the chemical composition of the drainage water furnish valuable data for future work along the lines of reclamation.

The following table gives the quantity of alkali in the tract, as shown by the surveys taken at different times:

Quantity of alkali in different depths of soil on certain dates.

Soil section.	September, 1902.		May, 1903.		October, 1903.		October, 1904.	
	Alkali in 40 acres.	Part of total.	Alkali in 40 acres.	Part of total.	Alkali in 40 acres.	Part of total	Alkali in 40 acres.	Part of total.
	Tons.	*Per cent.*	*Tons.*	*Per cent.*	*Tons.*	*Per cent.*	*Tons.*	*Per cent.*
First foot	1,363	20	499	14	101	8	38	4
Second foot	1,540	23	650	19	183	15	128	13
Third foot	1,766	27	1,066	31	330	28	212	24
Fourth foot	1,982	30	1,265	63	607	49	500	57
Total	6,651	....	3,480	....	1,221	....	878	....

The alkali removed from the first foot of the tract between September, 1902, and October, 1904, was 97 per cent of the total quantity originally contained; from the second foot, 91 per cent; from the third foot, 87 per cent, and from the fourth foot, 75 per cent. These figures show that to 4 feet depth there has been 86.8 per cent of the original alkali removed from the entire tract.

Compared with its condition in September, 1902, the first foot of the tract contains only 3 per cent of the alkali originally carried; the second foot, 9 per cent; the third foot, 14 per cent, and the fourth foot, 25 per cent. We find from this that the alkali has been removed most rapidly from the lower depths of the soil. We must remember that the alkali in the first 3 feet of soil must pass through the fourth foot in its movement downward. The fourth foot we find has been traversed by the alkali lying above it, and has yet lost 75 per cent of its own original alkali content. The extreme saltness of the percolating water has, however, made the final elimination of alkali from the lower 2 feet of soil progress more slowly than in the surface 2 feet. At the present time little more alkali remains in the first 2 feet of soil, and the elimination from the third and fourth should go on more rapidly.

The following table shows the increased acreage of soil containing a low percentage of alkali. The columns headed September show the original acreage, while the columns headed October show present acreage:

Acreage of land of different grades of alkali September, 1902, and October, 1904.

Per cent alkali present in soil (grade).	First foot.		Second foot.		Third foot.		Fourth foot.		All 4 feet.	
	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.
0.0-0.2	None.	38.8	None.	27.6	None.	17.0	None.	11.5	None.	23.7
0.2-0.4	3.0	None.	0.4	8.2	0.1	11.5	0.1	9.0	0.9	7.2
0.4-0.6	13.3	None.	2.3	3.2	.7	5.3	1.3	6.0	1.9	3.6
0.6-1	10.7	None.	8.0	None.	3.9	3.5	6.2	5.3	7.2	2.2
1-3	16.8	None.	19.7	None.	22.6	1.7	18.1	7.2	19.3	2.2
Over 3	5.0	None.	8.4	None.	11.5	None.	13.1	None.	9.5	None.

Operations for reclamation in 1904 began in April. An alkali survey made at that time indicated that the tract was in a fairly good condition as to alkali content.

Preparations were made for a crop test, and on May 10 the Utah Experiment Station began seeding the tract to three varieties of grain—wheat, oats, and barley—one-third of the tract to each variety. The seeding operations were finished on the 24th of May.

The general tilth of the land was not altogether favorable. The soil of the tract partakes somewhat of adobe characteristics, tends to bake or harden, and does not readily respond to cultivation. The flooding operations carried on the previous season had a tendency to compact the soil and disturb somewhat its physical properties. The tendency to bake is, however, a common characteristic for all soils in the vicinity at present under cultivation.

The first irrigation was given to the crop June 15. The part of the crop sown in early May had remained in the ground during this time without any appreciable amount of moisture. The surface of the land had hardened, and an examination showed that, while the seed had germinated, the young plants often failed to get through the upper hardened soil layer, and lay alive, though wrinkled and distorted, beneath the baked surface. No material growth was made prior to the first irrigation. Of the three grains sown the wheat made by far the best showing. This crop was, however, sown last, and did not receive water until twenty days after being planted. A close study of the soil and crop during May and early June showed that here and there small patches of alkali remained. These spots were strongly enough infected with alkali to prevent the germination of a part of the seed, though the general appearance of the soil was satisfactory.

The first irrigation given the crop materially improved the physical condition of the soil. An estimate on the germination of the crop showed that about 85 per cent of the seed had sprouted. Of the 40 acres about 15 per cent showed a thin stand due to alkali. The entire field headed short and showed the untoward influences of late seeding, late maturing, and the effects of alkali still remaining in the soil. One-half of the tract was ploughed under in early August and the remaining half in early September; this being done to improve the soil tilth.

The alkali found near the surface on the Salt Lake tract in April, 1904, owed its presence largely to the uneven surface of the land. Slight ridges occurred here and there and prevented uniform flooding. During the past two seasons numerous evidences have shown that the maximum quantities of salts were eliminated from the lands that were most deeply and continually flooded.

During September, 1904, the entire tract was turned over to the Utah Experiment Station for future cultural trials. Ten acres were seeded to winter wheat. The seeding was completed about the middle of October, much too late to secure the most favorable conditions, as at this time no water was available for irrigation and the soil was so dry that the grain lay in the soil for a long time before fall rains furnished sufficient moisture for the seed to germinate. In the spring of 1905 most of the wheat had made a good growth, but was thin and uneven in some places. The heads filled nicely and the wheat was pronounced by all who saw it a fine quality of good heavy wheat. The remaining 30 acres were planted to alfalfa and a great variety of other crops, including potatoes, corn, berseem, beans, hemp, sugar-beets, oats, barley, and spring wheat. As the land even at this late date had not been sufficiently leveled to irrigate the crops to good advantage, many of the crops suffered in consequence. In all parts of the tract, however, where sufficient water could be given the growing crops, the results were very gratifying. The crops made good growth and the yields were all that could be desired. In January, 1906, 13 acres of the tract had a good stand of alfalfa and 4 acres were in wheat. Systematic flooding was not carried on during 1905, but the tract was irrigated once a week the early part of the summer. Within a few hours after the irrigation water was turned on, the drains responded with an increased flow, showing that they were still as effective as when first installed. Careful tests made in June, 1905, and again in September, showed that the alkali content had changed but little, if any, from the preceding year.

FRESNO TRACT, CALIFORNIA.

Early in 1903 the reclamation of a 20-acre tract was undertaken near Fresno, Cal. From 1903 to August, 1905, the work was in charge of W. H. Knox. Since the later date W. W. Mackie has been in charge. Circular No. 11 was published by this Bureau in September, 1903, which described the conditions at that time. The following report, taken largely from this circular, describes the progress of the reclamation work to date.

At the time of settlement of the country south of Fresno there was little indication of the presence of alkali in the soil and no one then suspected that serious damage would result from irrigation. When, after a few years, alkali commenced to show in the vineyards and orchards, the attention of thoughtful men was directed toward remedying the evil, but up to the time of undertaking the experiment in 1903 nothing effective had been accomplished.

In 1900 a party from the Bureau of Soils spent a season in studying the soil conditions around Fresno, and in a report, embodied in the Report on Field Operations of the Division of Soils for 1900, recommended drainage, with frequent cultivation and copious irrigation during reclamation, as the solution of the alkali problem.

The Bureau selected a 20-acre tract of land belonging to S. M. Toft and N. H. Hansen, situated on Fig and Central avenues, about 4½ miles south of Fresno, and entered into cooperation with these gentlemen to demonstrate to the people of the Fresno district that alkali lands can be economically reclaimed.

The history of this land, as given by the owners, is as follows: The northern part of the tract was settled upon by Mr. Toft in 1876 and at that time showed no sign of alkali. In 1889 Mr. Toft bought an additional 20 acres at $350 an acre, an average value for land in that vicinity at that time. The southern part of the tract was first settled upon in 1862 by Mr. Hansen, and at that time was partially alkaline. It had never produced good crops. In 1890 alkali commenced to show on the northern part, and in 1898 and 1899 it was practically abandoned.

The tract lies in a level district where it was impossible to obtain a gravity outlet for the drainage water, except by digging a drain 2 miles long, so in order to raise the drainage water to the surface of the ground a chain pump operated by a water-wheel was installed on Central Canal, where it crosses Fig avenue. A drainage system of this kind is admittedly not so desirable as one in which a gravity outlet can be maintained.

Three-inch, 4-inch, and 6-inch tile were laid over the tract at an average depth of a little over 3 feet and 150 feet apart. The original intention was to use nothing smaller than 4-inch tile, but the makers were unable to supply enough tile of this size, so the deficiency was made up by using 3-inch tile. It was found impossible to lay the tile during the summer season, owing to the nearness of the water table to the surface and the resulting condition of the subsoil, which was too soft to permit the digging of a deep ditch. The work of ditching was commenced in December, 1902, and was completed in February, 1903. The cost of ditching, tiling, and all incidentals except the cost of pump and water wheel amounted to $16.50 per acre. The contract for the tile delivered in Fresno was, for 3-inch tile, $24 per thousand; for 4-inch tile, $32 per thousand; and for 6-inch tile, $72 per thousand.

At the time of the installation of the drains 18 acres of the land contained too much alkali to produce a crop. Scattered over a part of the tract were small patches of alfalfa and an occasional fruit tree—remnants of former cultivation. About March 1, 1903, irrigation was commenced. The land was divided into 30 checks, the size of each check depending upon the slope of the land. The largest checks, those on the level land, are about 2 acres in extent, while on the steeper slopes they are less than half an acre. The object was to divide the land in such a way that it could all be kept under water to a depth of 4 inches, and the reclamation was to be accomplished by maintaining the water at this depth until enough alkali had been washed out of the soil through the drains to enable a crop to be grown.

During the progress of flooding many difficulties were met, among them that of keeping the tiles from partially filling with sand and silt. Precaution was taken in laying the tile to put them in so the joints would be close, hay was thrown over the tile in the ditch before covering with earth, and a ridge of earth was thrown up to prevent the water from standing directly over the drains. In spite of these precautions the soil, which is very light, was so easily moved by water that it seemed to enter the joints almost as readily as did the water. This resulted in some of the drains becoming clogged, and it was necessary to relay a portion of the tile. Most of the trouble was with the 3-inch tile, which is admittedly too small for use in soils of the light and silty character of the Toft-Hansen field. It is thought that there will be more or less silting up of the tiles whenever they are used in the sandy and white ash soils of the Fresno district, and it is recommended that every possible precaution be taken in putting them in. Much of the trouble may be obviated by using no tile smaller than 4 inches or preferably 6 inches in diameter, and by giving the laterals such fall that the velocity of the water will be great enough to wash out the sand as rapidly as it enters the joints. The tile on the Toft-Hansen tract have a fall of 1 in 1,000 and the velocity of the water flowing through them is not sufficient to remove the sand.

During the season of 1903 the flooding was carried on from March to August. In 1904 flooding operations were resumed on February 11 and continued until August 22. Much of the land was reclaimed to such an extent during 1903 that crop tests were made. In July, 1903, one check or plot was sown to sorghum and one check to alfalfa. Clover did not succeed well, but 50 per cent of a stand was secured on 3 acres. In November, 1903, alfalfa was sowed on 3 acres. This started nicely, although it was somewhat damaged by frost.

In April, 1904, the first cutting of alfalfa was made. The total yield was about half a ton. Immediately following this cutting gypsum to the extent of about 400 pounds per acre was applied. This acted as a stimulant to the plant and also improved the physical condition of the soil. A second cutting of alfalfa was made in May, yielding about 2 tons. A third cutting was made in June and a fourth in July, the yield being about 3½ tons at each cutting. The fifth crop was a failure, owing to the depredations of the army worm. A sixth cutting was made in October, yielding 2½ tons. The total yield for the season and the value of the same are given below:

	Pounds.
First cutting, April	1,000
Second cutting, May	4,000
Third cutting, June	7,000
Fourth cutting, July	7,000
Fifth cutting, August	1,000
Sixth cutting, October	5,000
Total	25,000

12½ tons, at $7.50 per ton=$93.75.

On the north part of the tract some plots were sown to wheat. In June the wheat on checks Nos. 31, 32, 33, and 34 was cut for wheat hay, yielding as follows:

Checks 31, 32, 33—5 tons wheat hay, at $8.50 per ton	$42.50
Check 34—11 tons wheat hay, at $8.50 per ton	93.50
Total	136.00

Total value of crop of alfalfa and wheat, $229.75 from approximately 7 acres—$32.82 per acre.

An alkali survey, made in October, 1904, showed a total of less than one-fourth acre containing over 0.2 per cent total soluble salts. Of the black alkali there was approximately half an acre containing over 0.03 per cent black alkali and less than one-eighth acre containing more than 0.10 per cent. In every case the hardpan is close to the surface. Not only was there a marked change in the quantity of alkali the soil contained, but an even greater change in the general appearance and physical condition of the soil. The slick greasy appearance had given place to a dark, rich appearance, the tendency of the soil to bake had gone, and in its place was a friable granular condition.

This shows in conclusive manner the good effects of two seasons of flooding on a tract of land that had been practically abandoned on account of the rise of alkali. Alfalfa was sown on much of the land late in the fall of 1904, and by the spring of 1905 had made a fine growth. From three cuttings of alfalfa 25 tons of hay were harvested, valued at $5 a ton. Later in the season the troublesome Bermuda grass began to make its appearance and crowded out some of the alfalfa. Three acres were planted to White Australian wheat that produced a crop of 5 tons of hay, valued at $8.50 per ton. Smyrna barley planted on 3 acres produced 8 tons of hay, valued at $8.50 per ton. While the crop returns on this tract have been very satisfactory, showing that practically all the alkali has been leached from the soil, there are three factors that have retarded the final success of the work. These are the existence of hardpan in some places, which retarded the movement of water through the soil when the tract was being flooded; the clogging of the tiles, caused by the fine micaceous silt that enters them almost as readily as the drainage water; and the difficulty of removing the immense volume of drainage water. The presence or absence of layers of hardpan through the soil can only be determined by a careful study of any particular field. Its presence affects the rapid reclamation of any piece of land, especially when the hardpan is near the surface. On spots underlain at a depth of less than 2 feet by a firmly cemented hardpan it was found very difficult to leach the alkali beyond this layer. Even after the alkali had been leached through the hardpan the crop of young alfalfa was badly scalded by irrigation during the extremely hot weather. To overcome the difficulties caused by the tiles becoming clogged with silt and to remove the great inflow of ground water rising shortly after water is turned into the canals it was considered advisable to install a new drainage system, much deeper than the original. The work of installation was completed in the fall of 1905. More fall was given all lines of tile. No tiles smaller than 4 inches in diameter were used, and silt boxes were put in at the junction of all laterals with the main drain. A steel-wire cable, to which a brush can be attached, was also laid in all lines of tiles. This can be drawn through the tiles as often as seems necessary to keep them free from silt. The owners of the land have also doubled the capacity of the pump, so that in the future it should be adequate to remove all the drainage water. It is thought that no further trouble will result from the tiles silting or the ground water rising above the tiles.

NORTH YAKIMA TRACT, WASHINGTON.

In 1901 the Bureau made a detailed study of the soil, underground water, and alkali conditions in the Yakima Valley, Washington. In the report of this area Jensen pointed out the extent of the damage caused by alkali and suggested methods looking to the reclamation of such lands. In the chapter on Drainage and Reclamation of Alkali Lands Jensen writes as follows:

> If the soil is originally alkaline, there is but one sure and permanent cure for the trouble—that is, to dissolve out the excess of soluble salts by moderate but frequent application of good water, at the same time draining the water out of the subsoil, the process to be continued until the excess of salt has been removed.
>
> More especially is this true in case of the areas that have become damaged by alkali by allowing the subsoil water to come near enough to the surface to form an accumulation of salt by evaporation, in which class are the damaged lands in Wide Hollow and Atanum

Valley. The salts accumulated in these places are alkaline carbonates or black alkali, and an examination of the seepage water shows that it carries in all cases more than a normal amount of bicarbonate, but no normal carbonate. Examination also shows that the seepage or subsoil water is sufficiently near the surface to be brought up by the capillarity of the soil grains to the surface, there to be evaporated. There can be but one consequence—the comparatively harmless bicarbonate will lose through evaporation some of its carbon dioxide and be converted into the normal carbonate. As the soil is light in texture in this area this capillary action goes on quite rapidly; but, on the other hand, there is this advantage—the water can be removed from it correspondingly easier.

The alkali in the Wide Hollow and Atanum areas has originated from the seepage water brought down from the lands above. It will be quite useless here to try to effect a permanent cure by attempting to change the character of the salt by application of some other salt—as calcium sulphate, for instance—for, while this will change some of the black alkali to white alkali, it only adds more salt to a surface foot, already containing an excess, without in the least decreasing the tendency to form black alkali, which will continue to accumulate as long as the subsoil waters containing bicarbonate are near enough the surface to be evaporated.

In some areas in Wide Hollow the dangerous practice obtains of allowing the seepage water from above to subirrigate the land. This is a very good method of increasing the salt content of the soil, and the nearer the water approaches the surface and the longer the practice is continued the more salt there will be accumulated.

The Wide Hollow waste slough forms an excellent natural drainage channel for the lower portion of Wide Hollow, from sec. 36, T. 13 N., R. 18 E., and below. This goes through much of the salty area, and is from 5 to 10 feet below the surface of the soil. The soil is light in texture, readily permitting the water to percolate through it, and frequent applications of water, with a few drains about 4½ to 5 feet deep, would accomplish much toward reclaiming the land. Another good natural-drainage channel is the northern branch of Atanum Creek. It does not drain as large an area of the alkaline lands as the waste slough, neither is it as deep, but much of the land in the eastern part of T. 12 N., R. 18 E., could be reclaimed by draining into it. Atanum Creek itself would take care of the area between it and the branch just mentioned. A drain 4½ to 5 feet deep, containing rocks covered with willows, and this in turn covered over with soil, would effect this, but tiles will be found more economical. Even open drains, where they would not interfere seriously with cultivation, would serve very well.

The area selected for demonstration in the Yakima Valley is located about 3 miles south of North Yakima and contains 22½ acres. L. C. Holmes has had charge of the experiment from 1903 to the present time. It comprises a part of the southwest quarter section of sec. 31, T. 13 N., R. 19 E. The soil consists of a fine sandy and silty loam. It is light and porous and is made up to some extent of volcanic ash. Calcareous hardpan was encountered at a depth of from 2 to 2½ feet. The tract was virgin land, which supported only salt grass, greasewood, and some sagebrush. It was of no value except for pasture land and possessed a nominal value of from $10 to $15 an acre. Since good alkali-free soil in the valley ranges from $150 to several hundred dollars an acre and is very scarce, the importance of reclaiming such land, if possible, is at once apparent. The soil contained large quantities of sodium carbonate, sodium chloride, and sodium sulphate. The black alkali was largely in the first foot, while below the hardpan little or no alkali was found.

A complete drainage system was installed early in the summer of 1903. Six lines of 4-inch drains were laid 150 feet apart. These discharge into Wide Hollow Creek, which flows past the southern end of the tract. The tiles were laid at an average depth of from 3½ to 4½ feet, with a fall of 2½ feet in 1,000 feet. The tile was purchased in Seattle, Wash. On account of the light silty nature of the soil the joints between the tile were covered with tar paper. Experience at Fresno, Cal., had shown that with light soils every precaution should be taken against the silting of the tile, especially during the first few months that flooding is carried on, or until the earth settles firmly over the tile. The actual cost of the installation of the drainage system was about $21 an acre.

Flooding was commenced July 15, 1903, and continued throughout the irrigation season until about November 1. Considerable trouble was experienced with the unstable banks, the loose soil over the tile, and the steep slope of the land. The soil when freshly thrown up in banks or ridges does not hold water well, and with the slope of the tract it proved a difficult matter to hold the water on the land. Frequent breaks in the banks occurred and the lines of tiles had to be carefully inspected to prevent serious damage from the water washing earth into them. During the season of 1903 upward of 8,000,000 cubic feet of water was used, or sufficient to flood the entire tract to a depth of 8½ feet. Of this quantity approximately 25 per cent was carried away through the drains. The remainder passed below the drains into the deep subsoil, while part was undoubtedly lost through evaporation. Careful estimates showed that approximately three-fourths of the total alkali had been removed from the soil to a depth of 4 feet as a result of the season's flooding.

The work of flooding was resumed May 30, 1904, after the tract had been plowed and some of the checks had been more thoroughly leveled. During the season of 1904 the water supply was not as abundant as in the previous season, but about 4,500,000 cubic feet were used—sufficient to flood the entire tract to a depth of 5 feet. On account of the low condition of the water table only a small amount of this water passed through the drains.

An alkali survey made in October, 1904, showed that the quantity of alkali had been further reduced from the total amount originally present in the soil. To test the condition of the soil, the land was well prepared, and wheat at the rate of 2 bushels per acre was sown in the fall of 1904. Late in October, 1904, about 85 per cent of the tract was in good condition, as indicated by the young wheat crop.

The spring of 1905 found a part of the wheat, which had given evidence of a good start the previous fall, damaged by alkali. Nearly all the wheat which survived had a good color and was making a rank growth, but the stand was somewhat irregular. Rank grain was often found upon the sides of banks, but a few feet away the growth was patchy. The best soil, so far as the alkali content was concerned, often gave the poorest growth of wheat. These irregularities may be accounted for by one or more factors, such as the varying thickness of the hardpan, preventing thorough leaching of the soil, the leveling off of soil from one part of a check to another, or lack of aeration.

Alkali appeared on some of the land, especially on the high spots. Additional leveling was necessary to flood the entire tract evenly. The wheat crop was cut for hay, yielding about 25 tons, valued at $200. Some of it was over 6 feet in height. Flooding of the tract was begun about May 15 and continued until about September 30. The available water supply for flooding was not as great as in the years 1903 and 1904. It was estimated that over 6,000,000 cubic feet of water was used during the season, sufficient to cover the tract to a depth of 7 feet. The six lateral drains discharged water quite irregularly, but it was estimated that the total discharge was approximately 25 per cent of the amount applied in flooding. Usually 5 or 6 checks were selected and flooded repeatedly without giving the alkali a chance to return to the surface. Much trouble was again experienced with the unstable banks.

An alkali survey made during October showed that about one-fifth of the tract contained less than 0.05 per cent; three-fifths contained from 0.05 to 0.1 per cent, and the rest more than 0.1 per cent of alkali. The soil was in good physical condition, and its natural good tilth had apparently not been destroyed by the repeated floodings.

During September and the early part of October, 1905, the tract was plowed and seeded to wheat and alfalfa, 1 bushel of wheat and 15 or 16 pounds of alfalfa being used per acre. The early growth of these crops was quite favorable, but late spring freezes, which occur occasionally in the valley, were so severe that reseeding was necessary on the greater part of this tract.

TEMPE TRACT, ARIZONA.

A report on the soil survey of a part of the Salt River Valley, published in 1900, pointed out the trouble with alkali experienced by the farmers and made specific recommendations for the reclamation of affected lands, but no attempt has been made in this direction. Since the Bureau believed that this would be an excellent place for demonstration work, a tract of 20 acres was selected in 1904. The land is situated about 2½ miles south of Tempe. J. F. Warner was placed in charge of the experiment. Prior to 1904 this field was uneven and contained many stumps and various kinds of brush and weeds. At the south end there were 2 or 3 acres of alfalfa that produced fair crops, although it contained some spots that were damaged by alkali. During the fall of 1903 barley was sown on part of the tract, but it failed to make much growth on account of alkali. On the north end of the tract there was a heavy growth of the alkali-resistant Bermuda grass in places.

Early in January, 1904, an alkali survey of the field was made, which showed that the alkali was very unevenly distributed over the field. In places the soil contained 3 per cent of alkali to a depth of 4 feet and in other places less than 0.10 per cent was found. The average amount, as shown by a large number of determinations, was 0.88 per cent. The greater part of this was found in the surface foot.

The work of installing the drain-tile system was completed early in March, 1904. The cost of installing the drainage system was as follows:

Tile	$114.50
Freight on tile	313.90
Labor, digging ditches, and laying tile	153.80
Lumber	29.90
Tools	18.25
Total	630.35

From this it will be seen that the single item of freight on the tile amounts to one-half the total cost of installation. No tile could be purchased nearer than southern California. If tile could be manufactured at Tempe, the cost of installing such a drainage system as this would be very materially reduced. The cost of installation amounted to about $32 per acre. Four lines of 4-inch drain tile were laid at a depth of from 3½ to 5 feet. The laterals were placed 150 feet apart and discharged into a main drain at the north end of the field. At the time the drainage system was installed the water table was about 9 feet from the surface. For several preceding seasons the rainfall had been light, and the water table was consequently low. At the time the soil survey was made in 1900 water stood for a part of the year on the surface and was near the surface over the entire tract.

Soon after the drainage system was installed the irrigation water ran low, and but little was accomplished during the early part of the summer of 1904. Heavy rains during August enabled the work of flooding to be resumed. Flooding was continued at intervals until the late fall. In October 9 acres were seeded to barley, and other parts of the tract were seeded to wheat and alfalfa. These crops started nicely, but were somewhat damaged by the exceptionally heavy rains of the early spring of 1905. In places the soil showed a tendency to bake badly, while some few high spots still showed the presence of alkali. During the year 1905 cultivation was practiced to overcome the bad effects caused by the excessive use of water in flooding, and the small alkali spots were further treated to free them from alkali accumulations. A 5-acre tract was seeded to sorghum and made a good crop. In January, 1906, 15 acres of the tract had a fair stand of young alfalfa upon it, which was seeded with barley as a nurse crop. The remaining 5 acres had been planted to barley alone, as in this portion of the tract it seemed advisable to continue growing some annual crop. It was feared that even if a satisfactory stand of alfalfa were secured it would eventually be crowded out by Bermuda grass. After two years of reclamation work this tract had a crop capacity equal to the best lands in the neighborhood, whereas formerly it possessed little value as farm land, and repeated efforts to farm it had resulted in failure.

BILLINGS TRACT, MONTANA.

In June, 1904, steps were taken toward the establishment of another experiment on a tract at Billings, Mont. Billings is situated in the Yellowstone River Valley, and great progress has been made in growing alfalfa for winter feed for the sheep and cattle that pasture on the adjoining ranges during the summer months. Shortly after irrigation was begun alkali commenced to appear, and the ground water rose rapidly, water-logging wide areas of the soil to such an extent that they soon had to be abandoned. An examination of certain parts of the valley made by the Bureau in 1897 and 1898 showed the extent of the damage, and when, in 1902, a detailed soil survey was made around Billings it was found the trouble had greatly increased. Even in the two years that have elapsed since the soil survey was made many fine alfalfa fields have been abandoned and now are heavily incrusted alkali flats. The farmers are fully aware of the seriousness of the situation, and many tracts of alkali land were offered for the demonstration station.

The tract selected is situated 1 mile west of Billings. A. T. Sweet was in charge of the work during 1904 and 1905. The land was plowed many years ago and all attempts made to grow crops were unsuccessful. It was covered partly with a scant growth of greasewood and in places a thick growth of salt grass. It also supported a few alkali-resistant weeds and scattering bunches of prickly pear cactus.

The soil taken as a whole might be classed as a heavy loam, but lacks uniformity and varies in texture from a sandy loam to a stiff clay. The lighter soil is found principally in the central and western part of the tract, but is not continuous over any considerable area, occurring rather in scattered patches. The heavier soil becomes very sticky and difficult to cultivate when wet and breaks into small cubes like adobe when dry. Locally it is known as "gumbo." In places the heavy soil becomes sandy at a depth of 3 or 4 feet, but in other places extends to the gravel. In the Billings drainage ditch, 640 feet east of the tract, gravel is encountered at a depth of 6 or 7 feet and probably extends under the entire tract, but in many places in the vicinity, where it has been reached, it is found to be cemented and almost impervious to water.

At the time installation was begun an alkali survey of the tract was made and the following results obtained, the borings being made to a depth of 4 feet: Fourteen and two-tenths acres, or nearly three-fourths of the tract, averaged over 1 per cent of alkali for the 4 feet; 4.2 acres averaged over 0.6 per cent, while the remainder, 1.6 acres, averaged over 0.4 per cent. The concentration of alkali was found to be greatest in the surface foot and usually decreased with each foot in depth. Taking the first foot alone, 15.8 acres were found to have over 1 per cent, while in the fourth foot alone only 5.4 acres averaged over 1 per cent. The concentration also varied with the texture of the soil, the higher percentage of alkali being found in the heavier soil. The water table varied from 4 to 5½ feet and the ground water was strongly impregnated, tests indicating over 2 per cent of salt in solution. No traces of carbonates were found, only slight traces of chlorides and a small amount of bicarbonates.

No tile could be purchased in the vicinity, and freight rates were almost prohibitive, but the local brickmakers at once recognized that by putting in tile machinery a demand could soon be created for their goods. The situation was canvassed among the leading landowners, and many agreed to purchase tile if it could be cheaply secured. As a result tile machinery was ordered at once and the contract for furnishing the tile to be used in the experimental work awarded to the local manufacturers.

It was soon ascertained that by mixing ground shale with the ordinary brick clay a fair quality of tile could be made. After several hundred feet of tile had been made the tile machine was broken beyond repair and tile was ordered from Kansas City. This considerably delayed the installation of the drainage system. The system consists of five lines of 4-inch drain tile laid 130 feet apart, the outer ones being 70 feet from the edge of the tract. They were laid at an average depth of 4 feet with a grade of from 0.24 to 0.26 foot per 100 feet. They empty into a 6-inch drain tile laid 20 feet from the east end of the tract and having a grade of 0.25 of a foot per 100 feet. The water from this is carried by means of a 6 by 8 inch box to a drainage ditch 660 feet east of the tract. At the junction of the main tile and the outlet is a 4 by 4 inch silt box, while similar boxes have been placed at each of the laterals 500 feet from the junction with the main.

The cost of installing the drainage system was higher than on any of the tracts hitherto installed. The long distance from Billings to Kansas City, where the tile was purchased, greatly increased the cost over what it would have been had the tile manufacturer at Billings been able to fulfill his contract. The hard clay soil was exceedingly difficult to dig and the price of labor in Montana is high compared with other Western States. The actual cost per acre was approximately $35. With the installation of larger and better machinery tile should be purchased at less than one-half the price which the Bureau was compelled to pay in order to complete the drainage system. This of course will greatly cheapen the cost of drainage, while employing farm hands for digging ditches will further reduce the total cost per acre. With tile manufactured in the vicinity it is believed that the cost of such work should not exceed $15 or $20 an acre.

The installation of the drainage system was completed so late that flooding was not attempted during 1904. During the spring of 1905 there was an unusual amount of rainfall in the vicinity of Billings, the precipitation for the months of May and June alone being nearly 9 inches, and while the rainfall delayed the work of preparing the reclamation tract for flooding it was highly beneficial in removing the alkali.

The tract was plowed in the fall and lay fallow until spring, when that part which had been covered by greasewood was found to be in good condition to be cultivated, but that part formerly covered with salt grass was still unworkable and remained as a tough sod.

In June the levees for holding the water on the tract were completed. Water was admitted from a ditch along the south side of the tract by means of three head gates and allowed to flow from check to check by means of boxes. By a proper adjustment of head gates and boxes a continuous flow was utilized. Two weirs were installed, one for the purpose of measuring the water used in flooding; the other to measure the drainage water.

On July 6 water was turned on, and after the checks had once been filled, which required several days, the entire tract was kept submerged almost continuously until September 30. At two short periods during this time, however, it was impossible to secure sufficient water to keep the entire tract flooded, but at no time was the alkali permitted to reaccumulate at the surface.

As soon as possible after the water was turned off an examination of the soil was made. For this purpose about 40 points on the tract were selected, each one being within a few feet of the point from which samples for examination were taken in June. This examination showed that there still remained in the soil an average of only 0.20 per cent of alkali, or approximately one-fifth of the amount which was there when flooding began and about one-seventh of the alkali which the soil contained at the time the tract was selected. An alkali survey made in June, 1905, showed conditions to be much better than they were the preceding autumn, not only in the total quantity of salts, but also in its position. This change is believed to have been due to the leaching of the freshly plowed ground by the spring rains, accompanied by thorough underdrainage.

In June the principal concentration was found to be in the second or third foot, while at the close of the flooding period it was almost uniformly in the fourth foot.

In performing this work sufficient water was applied to cover the tract to a depth of approximately 6 feet. The evaporation from the surface for the flooding period is estimated at 12 inches. The rainfall for the period was too small to be regarded, being only 1.37 inches.

Of the water which passed into the soil, one-half, or 2.5 acre-feet, was delivered at the end of the drain outlet, 40 rods from the tract, while the remainder passed into the country drainage surrounding the tract, or along the line of the outlet.

During the flooding season the salt content of the drainage water decreased from 900 to 325 parts per 100,000. As the tests show so little alkali remaining in the soil, a crop test will be made as early in the spring of 1906 as weather conditions will permit. This will show in a conclusive manner how far the actual reclamation has progressed and to what extent the tilth of the soil has been damaged by several months' flooding.

CONCLUSION.

From the above accounts of the various demonstration experiments it will be seen that where the work has continued for any considerable time there is every reason to believe in the ultimate success of this method of alkali reclamation. The expense of the work has in some cases been considerable, but it is the belief that it has been justified by the results obtained. In each case tracts of land were selected that were practically worthless on account of accumulations of alkali and also where little if anything was being done to check the damage being caused by alkali. In each of the five districts the alkali problem is a very serious one, and thousands of dollars have been lost through the ruin of once valuable lands.

It will at once be seen that the first step to be taken in reclaiming alkali land is to insure thorough underdrainage in the soil, and that in order to accomplish this lines of drain tile have been used, even though it involved the outlay of considerable capital. By many it will be asked, Was this expensive system of underdrainage necessary? Could not the same method as employed by the Pima Indians be used and the same results be obtained in each case? Again it will be urged that many of the farmers in the alkali districts are in an impoverished condition and can not afford to expend much money to reclaim their lands. Why is drainage necessary at all on the open porous sandy soils that are so prevalent in the arid portion of the country? In districts where the underground water is many feet below the surface undoubtedly the reclamation of alkali lands can be successfully accomplished without installing an underdrainage system. This may be the case, especially on high bench lands. By carefully leveling such lands and using sufficient water the alkali can be washed into the deep subsoil, and even the most sensitive crops can then be grown.

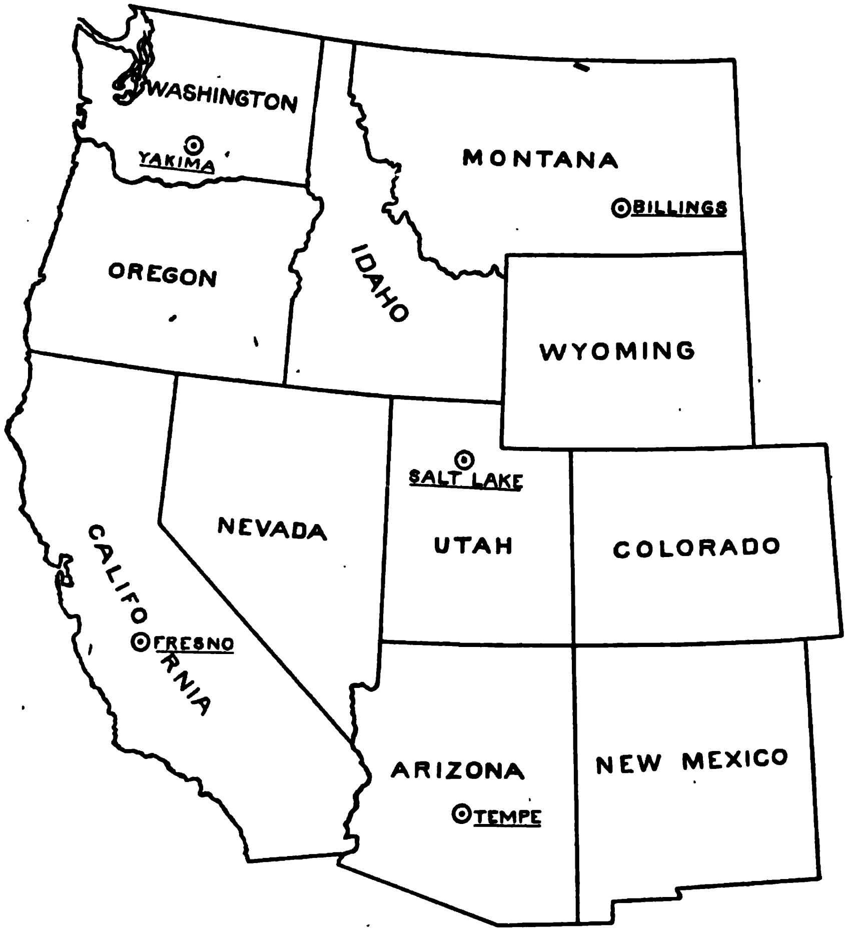

FIG. 13.—Location of alkali land reclamation experiment tracts, May, 1906.

Unfortunately the localities where excessive amounts of alkali have accumulated with a deep water table are comparatively rare. Generally the greatest accumulations of alkali in irrigated districts are where seepage waters have raised the water table until it is dangerously near the surface. Frequently it has been found that the damage and consequent abandonment of the land is caused by a combination of alkali and seepage waters. To attempt to reclaim such lands without lowering the water table is not to be generally recommended. Even with the surface soil free from alkali, the shallow water table would be a constant menace, since evaporation of this water would deposit on the surface whatever salts it held in solution. In the majority of cases even with a porous sandy subsoil it will be found that underdrainage will hasten the reclamation to such an extent that the income from the land in consequence of the rapid reclamation will pay for the cost of installing drainage. It is also to be noted that in a district with a high water table, if any large tracts of land are heavily flooded for long periods, the water table will be materially raised; so while it may be possible to reclaim a small tract without drainage it will be more difficult to reclaim large districts without providing some outlet for the excess of water used.

While the alkali question is at present of vast importance and demands serious consideration, indications point to its complete solution in the more important irrigated districts. In many of these districts extensive agricultural industries have been developed and good lands command high values. The time is soon coming when the farmer can not afford to allow alkali lands to lie waste and barren when the expenditure of comparatively small sums of money will make them productive. Intelligent land owners, as well as parties looking for profitable investment, will study the alkali question more carefully to determine just what methods will give them returns on apparently worthless lands with the least outlay of capital.

Constant search for more resistant crops will be made and the utilization of large areas of alkali land will be brought about in this way. Cultivation to mix the surface accumulations of alkali with the deep soil will also render some lands suitable for certain classes of crops. Surface flooding on carefully leveled fields will, in many instances, so reduce the alkali content in the upper layers of soil that some revenue may be derived from lands now abandoned as unproductive. The use of gypsum on lands containing black alkali will also increase the areas of reclaimed land and doubtless other methods of treatment will be found by those interested in returning once fertile lands to their former condition. These means are being successfully used to some extent in many districts at the present time and offer a strong incentive to other farmers by the same or other methods of treatment to attempt the reclamation of at least a portion of their alkali lands.

By their individual efforts, then, the farmers should strive to reduce the acreage of alkali on their farms until the time comes when the subject of regional drainage is provided for in each district. When that time comes the control of alkali will cease to be the vital problem that it is to-day.

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Issued July 27, 1907.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 42.

MILTON WHITNEY, Chief.

RECLAMATION OF WHITE-ASH LANDS AFFECTED WITH ALKALI AT FRESNO, CALIFORNIA.

BY

W. W. MACKIE.

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1907.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., April 24, 1907.

Sir: I transmit herewith a paper by Mr. W. W. Mackie, entitled Reclamation of White-Ash Lands Affected with Alkali at Fresno, California.

This paper discusses broadly, and mainly in untechnical language, the various questions entering into the problem of alkali land reclamation in the locality named. It includes the final results of the Bureau's work on the Toft-Hansen reclamation tract, where the redemption of lands from a nonproductive state to a condition making their use highly profitable has been successfully carried out.

This paper has been gone over carefully with Assistant Secretary Hays, who authorizes me to state that he concurs in my recommendation for its publication. This will be number 42 of the series of bulletins issued by the Bureau.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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RECLAMATION OF WHITE-ASH LANDS AFFECTED WITH ALKALI AT FRESNO, CALIFORNIA.

INTRODUCTION.

The present paper is written to show those farmers owning alkali land what treatment is necessary to make these lands as productive as the finest lands in the Fresno district. In discussing the relations of the soils of the Fresno district to alkali, however, it should be clearly borne in mind that only limited areas of those soils underlain by white hardpan are affected with alkali. The soils underlain by red hardpan contain but little alkali, and there is practically no danger that any serious damage from this source will ever result, and it is upon these alkali-free soils that the agricultural prosperity of Fresno has been firmly established. The accompanying sketch map (fig. 1) shows the position of the lands underlain by red hardpan and white hardpan and the areas of white hardpan soils affected with alkali. Of the 400,000 acres comprising the Fresno district 64,000 contain some alkali, but only 28,000 acres contain sufficient to prevent the growth of any useful crops. The remaining 36,000 acres contain only moderate quantities of the injurious salts and even in their present condition can be farmed with a fair degree of profit.

The country about Fresno is a vast plain intersected by the San Joaquin and Kings rivers and their tributaries. Before the advent of the Southern Pacific Company in 1876 the land was used for grazing purposes only, and many herds of cattle and sheep fattened on the native grasses and shrubs. These consisted mainly of foxtail or barley grass, salt grass, bunch grass, broncho grass, and filaree (Erodium).

The soils at this time were popularly classed as follows: The "red" soils, lying near the hills, the "white-ash" soils, found farther out in the plain, and the "white sands," or the extremely sandy soils associated with the white-ash soils. Where hardpan did not occur too near the surface the red soils were considered the best soils for all crops. The white-ash soils were not considered to have so wide an adaptation, but grew immense crops of grain and alfalfa. The sands or sandy soils were considered very poor and fit only for dry-farmed grain crops in wet years.

With the extension of the railroad system through the San Joaquin Valley, connecting San Francisco with the south and east, began the agricultural development of the Fresno region. At first grain crops only were grown, depending entirely on the annual rainfall, but recurring droughts soon forced upon the settlers the use of irrigation and the discovery that better and more remunerative crops than grain could be easily grown. Alfalfa fields soon produced green summer pasture and immense crops of hay as well. The small family orchard and vineyard of the settler were so fruitful that they were rapidly extended, and thus the fruit industry, which now overshadows all others, became paramount.

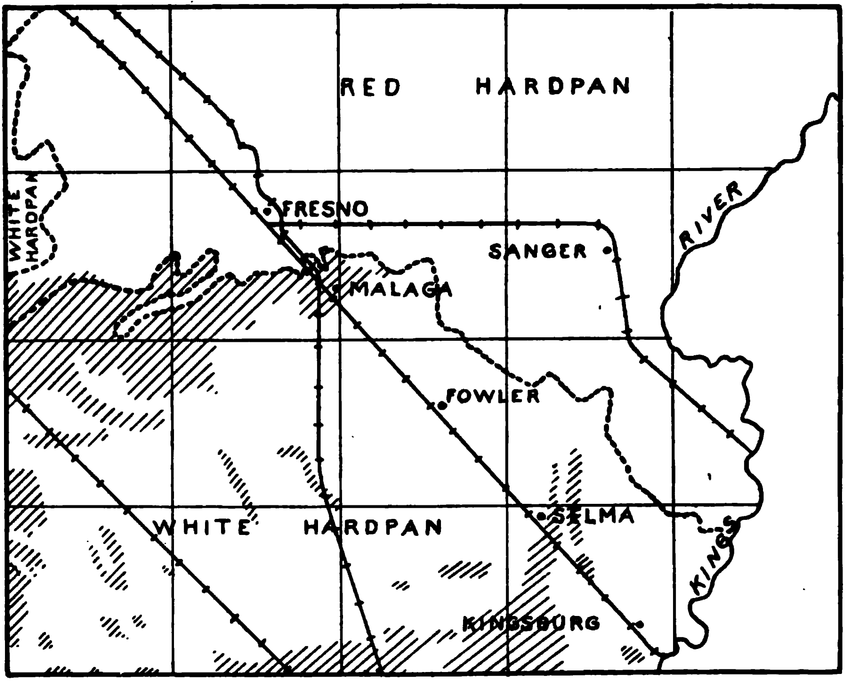

FIG. 1.—Sketch map showing areas of alkali land near Fresno.

The raisin grape, although grown at earlier dates in several parts of California, was soon cultivated at Fresno, especially in small vineyards. The first extensive plantings of Muscat grapes on the rich, level white-ash lands 3 miles southwest of Fresno proved so exceedingly profitable that a veritable rush began into raisin vineyards. Very soon an area of white-ash lands comprising about 20,000 acres to the southwest of Fresno was divided into small holdings, containing from 10 to 40 acres, devoted chiefly to vineyards, orchards, and alfalfa fields. Abundance of water from Kings River was assured, crops were good, and prices high. This full tide of prosperity continued until 1888 or 1890.

Alkali had always been present in the lower depths of the soil, but was visible only in isolated spots. It now began to appear in increasing and dangerous quantities on the surface. This rise or spread of alkali was due entirely to the rise and spread of the ground water.

Mr. Gustav Eisen, one of the earlier settlers on the red lands east of Fresno, states in his paper on the "Culture of the Grape in California,"[a] that in 1873, when irrigation water was first taken from Kings River, the water table was 65 feet deep, but that in 1878, after five years of irrigation, water stood at 6 feet from the surface of the soil.

In 1888, on the white-ash lands, the water table fluctuated between 2 or 3 feet from the surface in the spring growing season and 8 or 10 feet in the winter season. This water as it rose from the lower depths carried with it the alkali salts contained in the soil and upon evaporation from the surface the salts were concentrated within the zone of the tender rootlets of the annual crops. The concentration in alkali became exceptionally high in the surface foot of soil, thus preventing the germination of seeds. The caustic black alkali also burnt the young rootlets of the perennial plants.

The raisin vineyards first showed the evil effects of alkali by loss in crop yield, by less vigorous growth, and finally by burning and shedding of leaves in summer. On account of the proximity of hardpan to the surface in places where the soil is of heavier texture alkali had accumulated in greater quantities in these spots, and the vines soon died, while even in the surrounding vineyards where the vines were not killed the crops were so greatly reduced in quantity and quality that it became unprofitable to cultivate and harvest them.

Finally, about 1890, overproduction, financial stringency, and Spanish competition caused the price of raisins to drop so low that the crops barely paid for their production even in good vineyards. Hundreds of acres of vines were dug up and the land was replanted to alfalfa in the sweeter soils and to Bermuda grass where there was more alkali.

The decline of the raisin industry extended to 1898, when prices increased so that the cultivation of raisins became profitable again. Replanting began on an extended scale in the higher alkali-free lands nearer the Sierra Nevada Mountains, but few cared to replant on the white-ash lands, which were more susceptible to alkali damage. Because the area of good lands was limited, prices became almost prohibitive, with the result that the white-ash lands again came into notice.

During the period of rapid alkali encroachment many efforts were made to find remedies for the prevention and cure of the evil. The

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[a] American Grape Growing and Wine Making, by Geo. Husmann.

University of California[a] advised the reclamation of alkali land by heavy flooding to drive down the salts and underdrainage to remove them. The use of gypsum was also recommended to correct the caustic black alkali by transforming it into the neutral sodium sulphate or white alkali. The hardpan was given as the source of black alkali, and it was thought that gypsum would soften and disintegrate it until it would become pervious to water and roots. Farmers who applied gypsum to their lands derived no permanent benefit, for the black alkali and hardpan continued to exist where gypsum had been plentifully used. Underdrainage was not attempted on account of the nearly level character of the country and the shallow water table.

In 1900 the Bureau of Soils surveyed the Fresno district, including the white-ash lands affected by the rise of alkali, and constructed and published[b] soil, hardpan, and alkali maps. It was found that the white-ash soil, called Fresno sandy loam, of which 69,811 acres were mapped, contained the larger proportion of alkali found in the Fresno district, and that the Fresno sand, covering an area of 163,200 acres, had, through improper methods of irrigation, also become affected over considerable areas, the white hardpan and alkali occurring some distance below the surface. The area mapped in 1900 in the Fresno survey was 401,855 acres. The following table shows the extent of land of the several grades of alkali:

Areas of the different alkali soils.

Grades of alkali soils.	Acres.	Per cent.
0 to 0.20 per cent alkali	336,300	83.8
0.20 to 0.40 per cent alkali	26,300	6.6
0.40 to 0.60 per cent alkali	10,150	2.5
More than 0.60 per cent alkali	28,500	7.0
Total area	401,250	

These four grades for alkali soils are purely arbitrary. They are based on the average percentage of soluble salts in the soil to a depth of 5 feet. The relations of the several grades to crops are as follows: Those soils containing quantities of alkali up to 0.20 per cent are classed as alkali-free soils, such small quantities having no injurious action upon any crops. Upon lands of the next grade, those containing from 0.20 to 0.40 per cent of alkali, alfalfa and grain may often be profitably grown, but vines and trees suffer. Lands of the next grade—0.40 to 0.60 per cent—contain too much alkali for profitable crops, but when sufficiently moist they will grow Bermuda grass and certain hardy trees, like willow, cottonwood, eucalyptus, pomegranate, and fig. The last grade includes all land containing more than 0.60 per cent. The soils of this grade, under natural conditions, are worthless, except for a few weeds and salt grass, which afford scant pasturage, although when irrigated Bermuda grass thrives.

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[a] Bulletin No. 83, Cal. Expt. Sta.

[b] Field Operations of the Bureau of Soils, 1900, pp. 333–384.

From a study of the conditions at the time of the Fresno survey it seems that about 30,000 acres of the white-ash lands southwest of Fresno, previously in a high state of cultivation, had been injured by rise of alkali and were unprofitable for fruit culture. The Bureau pointed out that the arrest and cure of the alkali damage should first be commenced on those lands. The report stated that the question of alkali was resolved into two problems: First, to prevent good lands from accumulating sufficient alkali to injure crops; second, to reclaim lands already seriously damaged by alkali. It was shown that if the capillary rise of the water is retarded or prevented, whereby evaporation at the surface is reduced to a minimum, accumulation of alkali at the surface will be lessened or entirely prevented. Lowering the water table by drainage restricts the upward capillary movement of soil water, and breaking up the capillary spaces by culture is also effective in preventing alkali accumulations in good lands. To reclaim lands already containing alkali, deep underdrainage with copious surface irrigation was strongly recommended. The farmers were urged to take up reclamation, since in the greater number of cases the work was seen to be practical, for reclaimed land is almost always strong and productive, and, in fact, frequently better than land originally free from excess of alkali salts.

Soon after the completion of the Fresno soil survey the Fresno chamber of commerce and some enterprising landowners undertook to demonstrate on a small scale the efficiency of underdrainage in reclaiming alkali land. Unforeseen difficulties, however, influenced the chamber of commerce to abandon the work and to call on the Bureau of Soils to carry it to completion, and accordingly, in the fall of 1902, the Bureau laid a drainage system over 20 acres of the Toft-Hansen tract. Continuous flooding was carried on until large quantities of alkali had been removed and the reclaimed tract, which had been growing profitable crops for some time, was turned over to the owners in 1906.

The foregoing paragraphs have sketched in general terms the conditions around Fresno which led the Bureau to the undertaking of reclamation work in this district. The detailed steps in the actual work of reclamation will be given later, but before passing to this detailed account of the methods employed and the difficulties met and overcome in treating this alkali land, a further statement of the alkali problem and a description of the soils affected by alkali will be given.

SOILS AFFECTED WITH ALKALI.

In the report cited[a] four types of soil are designated as occurring within the alkali area. These are the Fresno sandy loam, locally known as white-ash land; the Fresno sand, the Fancher sandy loam, and the San Joaquin sandy loam. The Fresno sandy loam contained excessive amounts of alkali in all but a few places in the area. The other three types were much less affected.

The Fresno sandy loam occupies the level stretches of plain to the southward of Fresno, with a gradual slope toward the southwest. To outward appearance it is an ideal soil for irrigation. Where unaffected by alkali it is light gray in color, but where excessive amounts of organic matter and black alkali occur it is either brown or black. It is supposed to have been derived from volcanic ash. It is of loose texture, but forms clods when allowed to bake. At a depth varying from 2 to 5 feet white hardpan occurs, composed mainly of volcanic ash cemented together by calcium carbonate or lime. There are, however, enough fracture lines in the hardpan formation to allow sufficient percolation to secure good drainage under normal conditions. By excessive irrigation the water table has risen so high that alkali has been brought to the surface on this soil type. Capillary movement and evaporation of water have concentrated most of it in the surface foot, ruining the land for cropping. In those portions of this type lying between Selma and Sanger, where the water table has not yet risen high enough to cause injury, are found the finest orchards and vineyards in the country.

The Fresno sand occupies a position similar to the Fresno sandy loam, and is always found in close proximity to it. This type is a light-colored sand with just enough clay and silt in it to cause it to stand in banks. ' It is a rich productive soil, and was evidently washed over an area of white-ash soil and piled in uneven masses and hillocks, intersected by swales. Nearly always at depths varying from 3 to 8 feet the white ashy material of the Fresno sandy loam and white hardpan are found. On account of its great porosity, unevenness, and elevation above the surrounding types of soil it has been neglected, except where it comes in contact with other soils. In past years it was farmed to grain, but recurring droughts caused grain farming to be abandoned. Recently, however, the Fresno sand has been found to be excellent for peaches, alfalfa, peanuts, cantaloupes, and sweet potatoes. Pumps are being installed in many places to furnish irrigation water. On account of looseness of texture, frequent irrigation is necessary. As the water table on most of this type is below 10 feet at all times, very little alkali is found, save where the white hardpan lies near the surface. Where the Fresno sand borders the Fresno fine sandy loam, the water table is often close to the surface, and ponds frequently appear. For these reasons, and especially as it is sold at a comparatively low figure, there has been a great demand for this land.

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[a] Soil Survey Around Fresno. By Thomas H. Means and J. Garnett Holmes. Field Operations of the Bureau of Soils, 1900.

The Fancher sandy loam is a heavy sandy soil, in some cases approaching adobe in texture. It is a red soil which has been carried into the alkali area by streams and deposited in narrow bodies upon the white hardpan soil. It is usually more than 6 feet in depth over the hardpan and very uniform in texture. What little alkali it contains has been derived from the surrounding soils. This is one of the best fruit soils.

The San Joaquin sandy loam is a coarse red sandy loam underlain at 3 feet by red iron hardpan. It is free from alkali, except where it comes in contact with the Fresno sandy loam.

HARDPAN.

At Fresno there are two kinds of hardpan underlying the soils—the red and the white. Approximate boundaries between these two kinds of hardpan were given by Means in his alkali map of the area. (See sketch map, fig. 1, p. 8.) As stated in the introduction, the white hardpan area includes nearly all the alkali lands of the district about Fresno.

The red hardpan is a cemented sandy material, on the surface of which sheets of ferruginous character, showing a metallic luster, are often found. This hardpan, therefore, is really a ferruginous sandstone, and acts as such toward the penetration of roots and water.

The occurrence of white hardpan is very general. It extends in isolated bodies of various sizes from south of Bakersfield, in Kern County, at the southern end of the San Joaquin Valley, to Lathrop, in San Joaquin County, at the northern end. The greater proportion of it lies along the trough of the valley to the east of the San Joaquin River and Tulare and Kern lakes. It is intersected by streams from the Sierra Nevada Mountains which have washed it away, replacing or covering it with alluvial soils. In thickness it is much less than the red hardpan, varying from 2 inches to 5 feet in extreme cases. Quicksands or water-bearing sands usually occur below it. At greater depths beneath these sands other layers of white hardpan may be found. While the alkali east of the San Joaquin River is by no means confined to white hardpan soils, these hardpan areas contain the greater part of it. The surface of the hardpan is not parallel to the surface of the soil, for the overlying soil varies from 1 foot to many feet in depth. In thickness the hardpan increases toward the valley trough.

The white hardpan consists of silt, clay, and sand firmly cemented by carbonates of lime and magnesia and carries varying amounts of soluble salts. In places it is thin and broken, while in the thicker portions cracks often appear. Through these places water passes, and sometimes roots. As a body, however, it is practically impervious to water and roots of crops. When white hardpan is soaked in water for many weeks, it softens perceptibly and often becomes spongy, but although the hardpan softens during irrigation, it hardens again after the lowering of the water table in the fall. Chunks of it exposed to the sun and air for a year did not weather or break down perceptibly. In unirrigated lands alkali is found in large amounts immediately above this hardpan, though there are only small quantities in the overlying soil. In water-logged lands, on the other hand, the alkali usually associated with the hardpan has been carried up into the soil.

Hardpan seriously affects crops about Fresno in three ways—first, by interfering with the retention and conservation of moisture; second, by restricting the development of plant roots, which in most cases require 3 feet of soil, and, third, by causing the retention of alkali in the upper layers of the soil, ready to ascend to the surface, whenever poor methods of irrigation are practiced or the water table is raised. On account of the limited amount of soil, irrigation must be frequent to give crops the moisture conditions suitable for best growth, and yet too heavy irrigations drown or smother the roots.

ORIGIN, COMPOSITION, AND MOVEMENT OF ALKALI.

The alkali in the San Joaquin Valley, including that of the Fresno tract, is generally supposed to be the result of rock decomposition, which gives rise to the various soluble salts. These salts represent the last stage in the decomposition of the complex silicates, pyrites, and other minerals which make up rocks. In arid or semiarid regions like the San Joaquin Valley these salts are washed from the hills and are accumulated in the valley soils. The sulphates may be derived in part from the pyrites which on oxidation give rise to the various sulphates.

The alkali in the eastern side of the valley is contained mainly in the first few feet of soil. Black alkali is usually a prominent constituent in the salts of this region. The deep subsoil waters are uniformly low in injurious salts and are everywhere freely used for irrigation without the least danger. In the heavier phases of the alkali soils, especially where underlain at shallow depths by hard pan, alkali is accumulated and retained in quantity, as these soils are more resistant to leaching by flooding or rainfall. These conditions of origin and accumulation are particularly applicable to the alkali derived from the Sierra Nevada Mountains and accumulated in the soils east of the central trough of the San Joaquin Valley.

The alkali in the soils west of this valley trough are derived mainly from the leaching of the decomposing shales and sandstones which constitute the bulk of the rocks which form the Coast Range. This alkali consists largely of sulphates and is found uniformly in the soil to a great depth. Though no hardpan has been found to exist west of the trough of the valley, the rainfall has been too light to wash away the alkali.

According to Cameron[a] the alkali at Fresno is formed mainly by reactions between the chlorides of sodium and potassium and the carbonates of calcium and magnesium, giving rise to calcium and magnesium chlorides and sodium carbonate (black alkali).

The following table, giving analyses of nine samples, shows the composition of the alkali at Fresno:

Chemical analyses of alkali salts containing no sodium carbonate.

Constituent.	4872. Sec. 19, T. 14 S., R. 22 E., crust.	4841. Sec. 25, T. 14 S., R. 18 E., 0 to 12 inches.	4681. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4835. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4689. Sec. 2, T. 15 S., R. 19 E., 0 to 12 inches.	4831. Sec. 3, T. 15 S., R. 19 E., 0 to 12 inches.	4829. Sec. 31, T. 14 S., R. 20 E., 0 to 12 inches.	4877. Sec. 8, T. 17 S., R. 21 E., 0 to 12 inches.	4888. Sec. 9, T. 17 S., R. 22 E., 0 to 24 inches.
Ions:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Ca	18.71	12.59	1.60	9.51	Tr.	2.31	3.52	0.48	3.01
Mg	8.21	5.26	.74	3.30	Tr.	Tr.	Tr.	.16	
Na	5.34	15.56	31.11	21.28	33.78	32.41	28.74	33.77	34.19
K	.92	1.15	2.63	1.86	1.86	1.85	.59	1.81	.63
SO_4	1.00	1.60	25.84	4.54	11.97	5.55	3.81	5.44	7.24
Cl	64.60	60.40	33.39	54.55	29.92	36.49	4.99	8.06	2.41
CO_3					3.19	5.00	16.71	22.63	33.85
Conventional combinations:									
HCO_3	1.31	3.44	4.69	4.96	19.28	16.29	41.64	27.65	18.66
PO_4					Tr.				
$CaSO_4$	1.38	2.28	5.43	6.40		8.13	5.28	1.00	10.28
$CaCl_2$	50.64	34.61		21.08			[a] 8.21		
$MgSO_4$			3.66					.75	
$MgCl_2$	32.75	20.49		12.81					
K_2SO_4									
KCl	1.74	2.05	4.97	3.51	3.46	3.51	1.17	3.47	1.15
Na_2SO_4			28.25		17.69			5.50	
NaCl	12.32	35.77	51.23	49.39	46.68	57.31	7.04	10.72	3.04
Na_2CO_3					5.72	8.68	29.62	39.96	59.85
$NaHCO_3$	1.77	4.79	6.46	6.81	26.45	22.37	48.68	38.00	25.68
PO_4									
Per cent soluble	4.61	.87	3.50	.97	1.50	1.08	.68	3.75	1.91

[a] $Ca(HCO_3)_2$.

Assuming the conventional combinations, it will be observed that sodium chloride forms over 25 per cent of the alkali of this area. The average of 30 analyses of Fresno alkali shows that the total quantity of chlorides is about the same as the total quantity of carbonates and bicarbonates, which were present in about equal amounts. The sulphates occur in widely varying amounts from a mere trace to 20 per cent—the average for white-ash lands is close to 7 or 8 per cent, but in most water-logged lands it averages about 3 per cent of the mixed salts. One reason for this small proportion in the water-logged lands is probably the action of bacteria and algæ, which decompose the sulphates of the soil, giving rise to sulphurous gases, which escape.

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[a] Bul. No. 17, Bureau of Soils, p. 28.

As the capillary movement of soil moisture brings alkali to the surface, the alkali concentrates at the surface of the soil. In unirrigated virgin soils black alkali is found in varying amounts from the surface down to the underlying hardpan, but in irrigated soils with a high water table black alkali is seldom found in quantities deeper than a few feet. Sodium chloride (common salt) rises to the surface very readily, but is much more readily leached out by rain and irrigation water than the black alkali. During the process of irrigation comparatively large quantities of sodium chloride are present in the first drainage waters. After considerable water has passed through the soil, common salt decreases to small proportions.

The change of carbonates to bicarbonates is brought about by the action of water and of carbon dioxide,[a] while the reverse change of bicarbonates to carbonates is brought about by aeration or by the action of heat, which drives off carbon dioxide again. The ratio of bicarbonates to carbonates is also dependent on the concentration. This change has been demonstrated by evaporating drainage waters containing at the beginning no normal carbonates by exposing it to the sun for six consecutive days, or until the volume was reduced by 90 per cent. It was then found that there were approximately equivalent amounts of both carbonates present.

Cameron and Patten[b] percolated water through a black alkali soil. In the first percolates the normal carbonate was present, but on continued leaching soon disappeared entirely. The bicarbonates, however, continued to come out in considerable quantities, showing clearly that the carbonates reverted to bicarbonate in the presence of large quantities of water. These experiments agree with Hilgard's statement[c] that in order successfully to remove black alkali from the soil by leaching it is necessary to change sodium carbonate into another salt which is more readily leached.

Owing to its great absorption by soils, sodium carbonate tends to retain its position, while sodium bicarbonate seems to be absorbed to a much less degree. Moreover, bicarbonates are comparatively mild in their action toward seeds and plants, and in fact are far less injurious than the normal carbonates.[d]

The movements of alkali-carrying waters in the soil are varied. Immediately after rains the movement is downward because of the force of gravity. During irrigation by flooding this movement is also downward, but after flooding has ceased the ground water rises by capillary forces to compensate for evaporation at the surface. In this way alkali washed down in irrigation is again carried to the surface and the bicarbonates are reverted to carbonates as evaporation proceeds. The accumulation of salt at the surface is retarded when a mulch is formed, which hinders evaporation and the consequent capillary movement of moisture.

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[a] Bul. No. 18, Bureau of Soils, U. S. Dept. of Agr.

[b] Jour. Am. Chem. Soc., 28, 1646 (1906).

[c] California State Expt. Sta. Report, 1903, p. 65.

[d] Kearney and Cameron, Report No. 71, U. S. Dept. of Agr.

In order to determine how much alkali would return through capillary movement in baked soils, a plot in the Fresno reclamation experiment tract, well drained by tile, was allowed to bake for two months. The following table shows the changes in alkali content:

The results of capillary movements in tile-drained soils.

Depth in feet.	Per cent in soil.								Per cent.	
	Na_2CO_3.		$NaHCO_3$.		NaCl.		Total.			
	June 15.	Aug. 20.	June 15.	Aug. 20.	June 15.	Aug. 20.	June 15.	Aug. 20.	Gain.	Loss.
1	0.090	0.100	0.120	0.132	0.042	0.083	0.252	0.296	17.4	......
2	.081	.081	.120	.066	.067	.083	.268	.230	......	14.1
3	.016	.033	.100	.054	.050	.057	.166	.144	......	15.2
4	None.	.008	.084	.048	.050	.042	.134	.098	......	27.0
5	None.	.025	.108	.048	.117	.033	.225	.106	......	52.4

It will be noticed that the drainage water removed considerable alkali during the period when the surface soil was dry. An actual gain in alkali was made in the surface foot only. This capillary rise occurred only while the first 2 feet were drying out, and in this manner the alkali from the second foot rose, slightly increasing the amount at the surface. Like observations were made in other checks left during the hot weather. It was noticed that in places containing much alkali a distinct concentration of the salts occurred below the soil mulch, due to evaporation at this point. In other observations it was found that the soil mulch was not effectual in preventing some of the alkali from rising to the surface.

THE EFFECT OF ALKALI ON PLANTS.

When caustic alkali carbonates accumulate at the surface of a soil, the root crowns of young plants become seared and the tender rootlets become corroded. The salts which comprise the larger proportion of the alkali at Fresno—carbonates and chlorides—are especially injurious. Kearney and Cameron[a] have found the toxic limit for white lupine seedlings of single salts in solution and for combinations of salts. As a rule the combinations were much less toxic than single salts. For instance, the addition of sodium chloride or sulphate to a solution of magnesium chloride or sulphate, which alone is exceedingly toxic, reduces this toxicity many times. The addition of calcium chloride and usually calcium sulphate (gypsum) to solutions of sodium and magnesium salts greatly reduces the toxicity of the latter. The beneficial effect of gypsum in reducing the toxic influence of the alkali salts was observed at Fresno, for in some cases germination of alfalfa was effected only after the application of gypsum, and in other cases the growth of alfalfa was greatly helped.

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[a] Report No. 71, U. S. Dept. Agr.

The roots of such plants as fruit trees, vines, and alfalfa are provided with a thick protective parenchymatous tissue, which becomes corky on its outer surface and which prevents caustic action upon the growing parts if the concentration of alkali in the soil has been sufficiently reduced. During the growing season great quantities of water are taken up and discharged into the air, while the plant is elaborating material for its nutrition. The alkali salts are osmotically rejected and accumulate about the roots. In the late summer, when the water table is falling, the demand for water by the plant is very great and the roots have a harder and harder struggle to absorb this water from the alkali solution, which constantly increases in concentration. A dangerous quantity of alkali may enter the plant, causing various pathological conditions, such as the blackening of the outer portions of the leaves, yellowing, premature dropping of leaves, and weakening of growth, etc. The soil solution may even become so concentrated that moisture is actually drawn from the roots, collapsing the root cells and causing drought effects where in the absence of alkali sufficient water would be available for proper maintenance of plants. This concentration of alkali causes the yellowing and weakening of ends of branches, rosettes of leaves forming by condensing the internodes of the stem. This last symptom is frequent in the case of apple, pear, apricot, nectarine, and peach trees, though similar symptoms develop from other causes. In the case of alfalfa, this yellowing effect, where it is due to alkali, may be cured by heavy flooding. The yellowing and burning effect of alkali is also noticed in the case of hardy shade trees like the eucalyptus, pepper, and umbrella.

CROPS ADAPTED TO ALKALI SOILS.

As the land at Fresno became injured by accumulated salts, certain crops survived, or withstood alkali better than others. Farm practice has selected those best suited to the altered conditions. The following account gives the list of plants grown, with their adaptability to alkali.

With the encroachment of alkali, certain trees showed special adaptability, especially certain shade and ornamental trees. These include all the native willows and cottonwoods and the introduced eucalypts, elms, poplars, mulberries, and palms. Of these, palms and eucalypts seem to be the most resistant and are usually very thrifty.

Most fruit trees suffer severely from alkali, but the pomegranate, fig, olive, and pear, in the order named, are very resistant to all kinds of alkali. Pomegranates make excellent hedges, even in soils covered with a heavy black-alkali crust. Figs, especially the Mission and Adriatic varieties, thrive in alkali soils showing considerable alkali crusts on the surface. Poor drainage conditions do not appear to affect the growth and productivity of the fig. The olive is also a good tree for alkali soils and produces well where alkali is too strong for vines and alfalfa.

Grapevines are very sensitive, especially to black alkali. The lower limit for injury for total salts containing black alkali in the soil is between 0.12 and 0.15 per cent. Old vines established before alkali has become injurious often withstand considerable quantities where soils are deep and fairly well drained, but young vines are very sensitive. Of the vinifera varieties observed in the Fresno region the Muscat is by far the most sensitive, but all varieties suffer from comparatively small amounts. The Rose of Peru and the Feher Zagos in this section are more resistant to alkali than the other vinifera varieties observed, continuing to produce good crops where the others fail. Some of the American resistant stocks and some of their hybrids, with certain vinifera or European stock, show marked resistance.

Where alkali kills out spots in a vineyard or when a damaged vineyard is uprooted, alfalfa is usually planted. This often does well for a considerable time, especially where it is heavily flooded to drive down alkali accumulations on the surface. Where soils are too heavily charged with alkali to grow good alfalfa, wheat and barley are grown. Barley withstands greater quantities of alkali than any other cereal except, perhaps, rice. Barley produces good crops where orchards, vineyards, and alfalfa are killed. When the alkali becomes too strong for grain crops it is planted to Bermuda grass. Bermuda grass has been found flourishing in 6 per cent of black alkali. It seeds itself over the good soils by means of wind, stock, and canal waters, and by its stoloniferous roots. Its feeding roots have been found 9 feet deep in the soil, thus making it drought resistant. It is exceedingly difficult to get rid of and should never be planted except in hopelessly ruined soils. At the present time hundreds of acres are covered with Bermuda grass and considerable revenue is derived from the dairies supported by this grass.

Some soils containing too much alkali for the successful growth of alfalfa are heavily flooded and later plowed and sown to sorghum and Kafir or Egyptian corn. After a summer of this treatment alfalfa often grows well.

Many attempts have been made to introduce alkali-resistant forage plants in these alkali lands. The most promising was the Australian saltbush (*Atriplex semibaccata*). This plant grows well in black alkali soils and takes up considerable alkali, which is removed from the land when the plant is eaten by stock or cut for hay. It has been quite extensively grown in alkali lands at Fresno and elsewhere in the San Joaquin Valley, but, while the saltbush proves quite resistant to alkali and drought, it does not produce abundantly in the more droughty and worst alkali soils, nor is it palatable to stock when grown on such soils.

DEMONSTRATION WORK ON THE TOFT-HANSEN TRACT.

For their experiment in ridding land of alkali the Fresno chamber of commerce had selected a tract of land containing about 20 acres. This was situated about 4½ miles southwest of Fresno in the section where the first successful raisin vineyard was located, and consisted of the Fresno sandy loam (white-ash land). The land was owned by Messrs. S. M. Toft, N. J. Hansen, and J. M. Wilson. The original plan was to install a 6-inch tile drain 9 feet deep running north along Fig avenue. The drainage water was to be lifted from a sump 12 feet deep into a canal by means of a 6-inch piston pump driven by a wheel supplied with water from the Central canal. Two hundred feet of trenches were dug, but at a depth of 8 feet water and quicksand were encountered and it was found impracticable to continue the work. The Bureau of Soils was then requested to take up the unfinished experiment; and although it was clearly recognized that it would be exceedingly difficult to drain successfully a small narrow tract of porous soil, surrounded by water-logged lands, and with the ground water within less than 1 foot of the surface for months each year, the Bureau, on account of the interest manifested by the farmers of the vicinity, decided to carry to completion the reclamation of the tract already selected. The plan of removing the drainage water from a sump hole by means of a water-wheel pump also appeared objectionable. After due consideration of all these questions the Bureau of Soils entered into a three-year contract with the owners of the land. The owners of the tract, according to the terms of the contract, were to provide a sufficient supply of water for flooding, to level and check the land so that flooding could be carried on, and to maintain an efficient pumping system to remove all the water discharged by the drainage system into the sump. On account of the height of the ground water the installation of the drainage system was postponed until the fall of 1902, when conditions would be more favorable for opening trenches and laying tiles. In November, 1902, a drainage system consisting of a main drain 2,010 feet in length and nine laterals 3,650 feet in length was installed. As the tract was practically level, fall could only be secured by laying the main and laterals nearer the surface as they receded from the sump. On account of the extreme height to which the ground water rises at certain seasons and of the difficulties previously experienced with hardpan and quicksand it was decided to place the tiles at an average depth of 3 feet. The water table each year rose much higher than this depth and it was feared that the drainage system placed at a greater depth would be swamped by the rush of water from surrounding farms and would prove ineffectual. Six-inch tiles were secured for the mains, but a large number of 3-inch tiles had to be used in the laterals, as the order for 4-inch tiles could not be filled.

In Central canal a water wheel 14 feet in diameter by 8 feet in width composed of 18 blades had already been installed. By means of chain and sprockets a China pump elevator was attached which lifted the water through an inclined, tightly boxed trough.

As soon as the canal began to carry water flooding was commenced. At first the tiles drained nicely, but soon silt and sand washed into them and in places completely clogged them. The question of keeping the tiles free from silt proved very troublesome from the outset. The soils on the tract carry large quantities of micaceous silt which enters the tiles readily with the water. Many hundreds of feet of tiles were in this manner soon filled with silt, making it necessary to dig them up and clean them. At the next flooding this process of silting was repeated. Attempts were made to move the silt by placing silt boxes or manholes at the junction of the laterals with the main and from these openings to force spliced rods through the tiles, but the failure of the China pump to remove the drainage water as fast as it accumulated caused the tiles to become filled with silt in spite of efforts to keep them clean.

Meanwhile the flooding had been kept up and levees had been raised over the lines of drains in an attempt to prevent the water washing silt into them. At the end of the irrigation season an alkali survey showed that the injurious quantities of alkali had been driven down from the upper layers of the soil from all but a few spots, where hardpan closely approached the surface or where the land could not be deeply covered by irrigation water. Summer crops planted after the irrigation season determined to what extent reclamation had progressed. Some alkali soon rose again as a result of the close water table. Crops of alfalfa and grain were successfully grown during the next winter and spring, 1903–4, on the checks more fully reclaimed, producing $93.75 from 3 acres of alfalfa and $136 worth of grain hay from 7 acres, making an average of $23 per acre for the 10 acres in crops. During the season of 1904 the crops already growing were irrigated and the rest of the tract heavily flooded to remove fully the remainder of the alkali. Such success was attained by this work that in the fall of 1904 the greater part of the tract was sown to alfalfa and a fine stand secured. The appearance of the entire tract was quite promising and commented upon by all who had watched the progress of the experiment. Early in 1905 a bucket pump replaced the China pump, which had proved inefficient in removing the drainage water. This pump, however, never appreciably lowered the water over the tiles and soon became worn and required constant repair and attention.

On account of the height at which the water stood during the hot summer months large quantities of alkali which had been driven into the lower depths of soil by previous flooding again accumulated at the surface. In spite of this and of the inroads of Bermuda grass on the alfalfa, the total crop yield during 1905 was valued at $235.

The results of the experiment at the close of the irrigating season of 1905 plainly showed that the water table must be lowered to a greater depth to effect the permanent reclamation of the tract. It was evident that while the alkali could be washed from the upper layers of soil it would return to the surface just as soon as conditions again became favorable. In order to experiment further on lowering the ground water it was decided to install a deep and more extensive drainage system. It was realized that at a greater depth more water would be carried by such a drainage system and that a pump of greater capacity would be necessary. A new drainage system following out these ideas was next installed, the work being completed in November, 1905. The plans are shown on the accompanying diagram (fig. 2).

This diagram shows a main drain 2,010 feet long, into which flow nine laterals at right angles. Six laterals are each 500 feet long and three are each 210 feet long. At the intersection of the laterals with the main, silt boxes 6 feet long by 2½ feet in width and set 18 inches below the level of the tile were installed. Near the water wheel on Central canal, a sump box extending 10 feet below the level of the ground, 5 feet wide and 10 feet long, was constructed to hold the pumping machinery. In order to clean the tiles and avoid their clogging in the future, the plan employed successfully for the past fifteen years on the Sunnyside Vineyard east of Fresno was closely followed. This plan consisted in placing a one-fourth-inch, 7-strand, galvanized steel-wire cable throughout the whole length of the drains, in attaching wire brushes to the ends of the cables, and in pulling the brushes back and forth through the tiles with the aid of small hand windlasses. In this way three or four men can clean about a mile of tile a day under ordinary conditions. Thorough cleaning once or twice a year is sufficient after the soil is once firmly settled over the tiles. The flat steel wire brushes were patterned after those used to clean city sewers, modified to meet tile drain conditions. These brushes were made of exactly the same diameter as the tiles to be cleaned—4, 6, and 8 inches. To remove sand and silt an additional plug was made, having the wires replaced with iron washers from 1½ to 6 inches in diameter.

At the time the cable was laid the owners of the tract installed a new pump, with a double row of buckets, giving three times the number carried by the original bucket pump. Owing to the great strain, this pump proved inefficient and was soon replaced by a No. 3 horizontal centrifugal pump with a capacity of from 150 to 400 gallons per minute. In order to generate sufficient speed for the pump, the water wheel was geared up until the pump shaft made from 250 to 500 revolutions per minute according as the current in the canal varied. All the machinery was above ground except the pump, which could be quickly detached and lifted out of the sump. The substitution of the centrifugal for the bucket style of pump was completely successful and fully solved the problem of removing the drainage water and incoming silt.

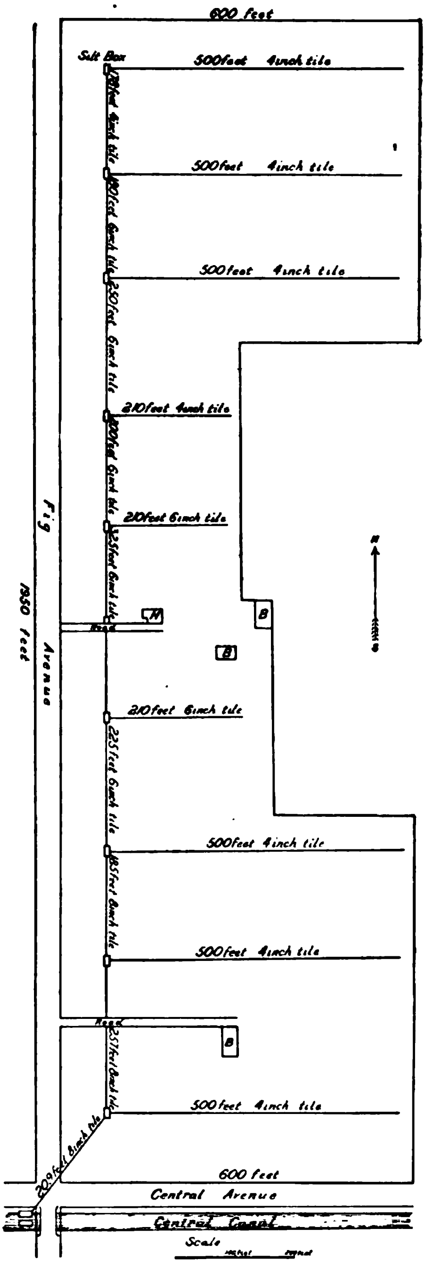

FIG. 2.—Plan of drains, Toft-Hansen tract.

FLOODING VINEYARDS FOR ALKALI BURN.

While the demonstration experiment was continuing on the Toft-Hansen tract, the opportunity to try the effect of flooding on grapevines affected with alkali burn was presented, and a careful study was made of the conditions before, during, and after the treatments. Two vineyard plots at some distance from the tract, but still within the influence of the drains, were selected for the tests. One vineyard was 20 years old and the other a young vineyard set but two years previously. The vineyards were staked at regular intervals, the stakes numbered, and each foot in the soil column analyzed for alkali before flooding. Analyses of soil at each stake were made as soon as the ground became dry after flooding, several weeks later, and at the end of the summer.

The first flooding in the old vineyard took place early in May. The irrigation was hasty, the water standing to an average depth of 3 or 4 inches only, and remaining over the surface for less than twenty-four hours. The vines showed improvement at once both in crop and in foliage. At the end of the season the vines about stakes Nos. 2 and 3 showed alkali burn, while those about No. 1 were fresh and green. Nos. 2 and 3 were flooded to a maximum depth of 2 or 3 inches only, while No. 1 had a depth of 8 inches over the soil. No. 1 lost more than half its alkali, while the soils about the other two stakes lost but a trace, thereby permitting alkali burn. In spite of this alkali burn, the largest crop in years was produced.

The analyses for alkali in the old vineyard, given in the following table, are those of samples taken from one of the locations marked by stakes. The conditions at this point were typical of the vineyard in general, and it does not seem necessary to multiply the data by presenting the complete records for all the stakes. The analyses show the amount of the salts removed by good irrigation to a fair depth, and the quantity returned to the surface during the summer, the latter being indicated by the difference in the loss shown on May 23 and on August 20, respectively. In some cases there was a gain in the quantity of salts found in the lower part of the 6-foot profile. Such gains, it will be noted, represent the alkali transported from nearer the surface but not carried below a depth of 6 feet. Such cases were, however, both in the old and young vineyard, greatly in the minority.

Results of flooding old vineyard to relieve conditions of alkali burn.

Depth in feet.	Na_2CO_3 in soil.			$NaHCO_3$ in soil.			NaCl in soil.		
	May 3.	May 21.	Aug. 20.	May 3.	May 21.	Aug. 20.	May 3.	May 21.	Aug. 20.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1..........	0.086	0.033	0.073	0.130	0.084	0.074	0.125	0.025	0.100
2..........	.020	.033	.041	.067	.072	.138	.067	.042	.113
3..........	.008	None.	Tr.	.078	.096	.120	.075	.058	.083
4..........	Tr.	None.	None.	.072	.068	.060	.095	.061	.067
5..........	None.	None.	None	.066	.054	.066	.067	.050	.053
6..........	None.	None.	None.	.066	.054	.048	.067	.050	.038

Results of flooding old vineyard to relieve conditions of alkali burn—Continued.

Depth in feet.	Total salts in soil.			Condition May 21.		Condition Aug 20.	
	May 3.	May 21.	Aug. 20.	Gain.	Loss.	Gain.	Loss.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.341	0.142	0.247	....	58.4	....	27.6
2	.154	.147	.292	....	5.9	10.4	....
3	.161	.154	.203	....	4.4	26.0	....
4	.167	.133	.127	....	20.4	....	24.0
5	.133	.104	.119	....	21.9	....	10.4
6	.133	.104	.086	....	21.9	....	35.4

While, as stated, the young vineyard treated for alkali had been set out two years previously, the majority of the vines had been replanted at the beginning of the second season. At the beginning of the third season, at which time the experiment was undertaken, the missing spaces had been filled with unrooted grape cuttings, and this third planting covered a large proportion of the 2 acres flooded. At the time of flooding many of the cuttings had commenced to die from alkali burn and the remainder were in bad condition. The water was held as deep as possible over the land, but some parts were so high that the water did not stand more than an inch or two deep at the maximum. The remaining portions improved at once, and the vines assumed a normal bright green and put forth a fine growth. This condition continued throughout the entire season, except on the high parts, where the water during irrigation was shallow. These parts were flooded again in August to offset the alkali drought effect, with great success in restoring the normal green in the leaves. Only a little water was used in August, for fear of sun scald. One week of flooding 6 or 8 inches deep in May did not injure a single vine by scalding.

At the close of the season the vines treated in this experiment were bright green and growing nicely, while the vineyard next to it and only 10 feet from the irrigated vines was denuded of most of its leaves, and none of those remaining was green. Analyses, taken from a typical boring, show the movement of alkali downward and toward the surface in each foot. The vineyard was kept well mulched during the time covered by these records. The remarks explanatory of the conditions in the old vineyard in general apply here.

Nearly all the soil before irrigation at the beginning of May contained sodium carbonate. After flooding, the soils at many of the borings entirely lost their sodium carbonate by conversion into sodium bicarbonate and by leaching. After nearly four months of summer weather much of the land was still free from carbonate, while the rest showed this salt in much smaller quantities than existed at the beginning of the experiment. Those soils covered deepest by flooding or having the more porous texture most readily lost the carbonates and remained more permanently free from them. Where the carbonates were completely removed, the vines showed the best growth.

When this flooding experiment was commenced, the vineyard was thought to be too far from the Toft-Hansen tract to be affected by the drainage system, but it soon became apparent that the land was well drained, which accounts in a measure for the rapid removal of the alkali. This experiment shows that flooding may be successfully practiced in early summer without injury to growing vines even when flooded for a week at a time.

GROUND WATER.

Before canals covered the Fresno plains with water the water table was more than 30 feet below the surface. Those soils near the Kings River were first irrigated and later the lands farther out in the valley. The first waters passed downward into the lower strata of soil, which were laid down in an old lake bed, and which slope downward more rapidly than the surface of the land and are the source of an artesian water supply. In the soils irrigated farther away from the river the water could not escape so rapidly on account of the red hardpan and on account of the substrata. Excessive irrigation soon filled the substrata, then the subsoil, and later the soil to within 2 to 3 feet of the surface, causing great destruction in orchards and vineyards over a large area. Instances are on record of as high as 27 feet of water having been applied to the surface during a single irrigation season.

Subirrigation was also practiced at Fresno, but was abandoned when the water table rose near the surface. Since then many vineyards, orchards, and alfalfa lands have not been irrigated for long periods of years. Where the soils contain no alkali, subirrigation is regarded by many farmers as beneficial rather than injurious. This is true of much of the red hardpan lands where little or no alkali exists.

Over a large part of the Fresno district the ground water now rises to within a few feet of the surface each year and drainage must be resorted to in order to prevent the widespread destruction in orchards and vineyards. It has been thought that leakage from canals was the cause of the rise of the water table, but an examination of the canals showed that they were cemented or puddled by deposits of fine silt from the mountain wash. This silt filters into the porous sandy soils and is packed under a great pressure of water for several months of the year. Only in the case of new canals or laterals is there any considerable leakage. This has been borne out by observations on the height of the water table both near and at some distance from the principal canals, the water table at the canal being at the same height as several hundred yards distance. These observations show that the condition is due almost entirely to excessive irrigation without proper drainage. Systematic drainage is therefore the only means of permanent relief from the ground-water injury over a large part of this area.

In some cases, especially in the red hardpan lands, drainage has been resorted to in order to save vineyards and orchards from injury due to ground water. Drainage systems on certain ranches have been very profitable and have been in successful operation for many years. The cost of these drainage systems has frequently been covered by increased yield of crops in two years' time.

ANNUAL FLUCTUATION OF GROUND WATER.

With the beginning of the irrigation season each year the upper lands fill with water, which moves slowly through the soil with the slope of the land. When the maximum height of ground water is reached many miles of country between Sanger and Ormus become more or less water logged. In the wells near the Toft-Hansen tract[a] it was found that during this period the average rise of water was one-half inch a day until a maximum was reached in May, or later during seasons of late spring snows and rains.

Observations taken on the Toft-Hansen tract of the height of ground water from September, 1905, to October, 1906, are given in the following table:

Monthly variation of the water table in the vicinity of the Toft-Hansen tract.

Date.	Depth to water table.	Date.	Depth to water table.
	Inches.		*Inches.*
1905, September 20	66	1906, April 1	36
October 20	78	May 15	36
November 20	84	June 15	24
December 20	102	July 15	24
1906, January 3	96	August 15	30
January 21	84	September 15	40
February 23	50	October 12[a]	68
March 10	44		

[a] Canal shut off September 24, 1906.

During the winter months there was not a continuous flow of water in the canal. The irrigating season ordinarily does not begin before the 1st of January, so that there is a period from October to January when the ground water reaches its greatest depth. It is during this period therefore that drainage systems requiring to be laid at a depth of several feet must be installed.

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[a] Observations taken during 1903 by the Office of Experiment Stations, and in 1904 by the Bureau of Soils.

A study was made of the daily fall of the water table at the close of the irrigating season of 1906. The records are given in the following table:

Fall of the water table at the end of the season.

Date.	Depth to ground water at sump.	Date.	Depth to ground water at sump.
	Inches.		*Inches.*
September 24[a]	100	October 6	65¼
September 25[b]	44	October 8	66¼
September 27	50	October 9	66½
September 29	55	October 11	67½
September 30	60	October 13	68¼
October 1	62		
October 2	63	Average fall for 18 days	1.375
October 3	64	Average for last 10 days	0.425
October 4	64½		

[a] Prior to shutting off canal. [b] Water shut off in canal and pumps stopped.

It will be seen that when the pump stopped the water rose 56 inches in twenty-four hours. Earlier in the season, on account of the saturated condition of the soils, a period of only four to five hours was necessary to raise the ground water to the same level. After the first day the ground water dropped rapidly, but later the fall averaged half an inch a day until the water sank to the depth of the silt boxes.

This fall agrees in rate with the rise of the water table at the beginning of the irrigation season. Elliott[a] also found that the ground water rose at the rate of half an inch a day until the maximum was reached for that season. From this concordance between the rise and fall of the ground water, half an inch a day seems to be the rate of the water movement through these soils under ordinary conditions, while drainage produces a more rapid movement of soil waters.

EFFECT OF DRAINAGE ON THE WATER TABLE.

It was found that the drainage system immediately lowered the ground water to the depth of the tile on the Toft-Hansen tract, except where depressions occurred in the hardpan. As the season progressed an increase in the flow of drainage water was noticed. On investigation it was found that cellars to the north and east of the tract had for the first time in many years become dry during the high-water season. Ponds half a mile away that in previous years had remained full until the canal was shut off in the late summer, now either became dry or nearly so.

In order to test this drainage at a distance the behavior of the water in the cellars drained was carefully noted. On stopping the pump, the cellars filled to their old level within twenty-four hours. When the pump was started, within twenty-four hours the cellars again became dry. This was quite noticeable in a cellar on Elm avenue, more than three-fourths of a mile away to the northeast and directly in the line of the country slope. Here the drainage was so complete that after the canals stopped running at the end of the irrigating season the land was free from water to a depth of 7 feet, while surrounding lands shut off from it by elevations in the hardpan showed water at 4 feet.

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[a] Report on Drainage Investigations, 1903, Office of Expt. Sta.

It must not be understood from these statements that water passed through three-fourths of a mile of soil in twenty-four hours. The water in the cellar was actually drained a short distance only, but all the water in the soil between cellar and sump was drained the same distance by this simultaneous water movement.

Conservative estimates at the close of the season placed the number of acres affected by the drainage system on the Toft-Hansen tract at 250. As the tile drains actually covered only 20 acres, it will be seen at once how far-reaching are the effects of drainage in these Fresno soils. The fall in this neighborhood is about 5 feet to the mile in a southwesterly direction. Consequently by securing a rapid passage of water through the soil by means of tile, together with the natural sand channels, the land above the drainage system in the direction of the natural slope may have the water table reduced to a lower level than the land immediately drained. For the same reason, much larger quantities of water must be carried through and away from land nearest the tiles in order to keep it sufficiently drained.

The land lying immediately below the tract in the direction of the fall of the country did not receive much benefit from the drainage beyond a few hundred feet, except as drained water was intercepted in its passage across the tract. This probably amounted to very little, as the land here is flat and the passage of water slow.

To accomplish this amount of drainage, a daily discharge varying from 200,000 gallons at the beginning of the season to 350,000 gallons for the middle and latter part was found to be sufficient.

The experiments on the Toft-Hansen tract, as well as numerous other examples of drainage, showed that the ground water can be kept at sufficient depth over a large number of acres with a comparatively small drainage system. At Selma a ditch constructed to connect ponds and depressions lowered the water table and at the same time carried away large quantities of alkali. In some cases the water table may be lowered over a considerable area by pumping from shallow wells, which should be 8 to 10 feet deep. At that depth water-bearing silt or coarse sand, which conducts water with great rapidity, is usually encountered, thus affecting a considerable area. One objection to this plan of pumping off excess drainage water is that the flow of water will not be sufficient to supply the pumping plant. When supplementary drainage ditches are used in addition to the pump the water is carried from a shallow depth of soil over a large area.

COMPOSITION OF GROUND WATER.

The following table gives the composition of the drainage water pumped from the tract at Fresno:

Composition of the drainage water of Toft-Hansen tract.

Date.	Ca.	Mg.	Na.	K.	SO_4.	Cl.	HCO_3.	CO_3.	Parts per million in solution.
1903.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	
Mar. 28	8.90	3.77	11.78	2.66	12.23	6.66	54.00	....	450
Apr. 25	6.91	6.06	7.88	2.18	4.85	8.85	63.27	....	824
May 2	3.59	4.15	16.35	1.75	2.39	8.95	60.99	1.83	1,251
9	3.57	3.64	20.49	1.58	2.06	9.62	51.82	7.22	1,454
16	3.58	3.76	19.72	1.44	1.88	9.69	54.79	5.14	1,592
23	5.36	4.28	15.47	1.76	3.06	10.73	59.34	....	1,306
30	2.07	3.47	23.55	2.00	7.01	10.55	40.63	10.57	1,639
June 6	3.01	3.15	22.84	2.35	6.45	11.79	40.50	9.79	1,495
13	3.24	2.96	22.70	2.19	3.91	13.35	43.32	8.29	1,048
20	3.81	3.21	21.82	1.87	2.79	11.78	54.19	....	1,494
21	3.20	3.38	21.09	2.82	2.63	9.88	56.96	....	1,062
July 4	3.06	2.27	20.82	2.63	4.98	6.12	57.21	2.97	1,143
11	3.60	1.69	23.04	3.77	6.38	18.09	39.32	3.90	768
1906.									
June 9	2.96	2.70	21.74	1.16	4.69	12.72	53.50	.53	1,109
23	....	....	....	....	....	....	....	....	864
July 8	....	....	....	....	....	....	....	....	944
21	3.28	2.95	21.74	1.13	3.17	13.60	51.07	3.06	883
Aug. 4	....	....	....	....	....	....	....	....	776
18	3.40	2.40	21.76	.62	2.86	12.00	56.96	....	1,117
Sept. 1	4.39	2.81	19.94	1.01	3.15	13.52	55.18	....	888
15	3.61	2.58	21.17	.93	2.89	13.12	55.70	....	968

The irregularities or variations in the analyses of the water for 1903 are due to the intermittent pumping, which was at the same time insufficient to reduce the water table to the level of the tile. With few exceptions the quantities of the various constituents of the soluble salts in these analyses compare closely with those for 1906, when the pump worked well and kept the water down to the tile, but the total salt content differs considerably. The analyses for 1906 show a very uniform proportion for the various constituents, with the exception of the carbonates. No normal carbonates were found at any time in the drainage water of the tract. The remaining slight variations are due in each case to a change in dilution from an increase in the flow of drainage water.

Cameron,[a] in his discussion of "the composition of the drainage waters of some alkali tracts," showed that this unvarying composition would necessarily occur until one of the solid components is entirely removed from the soil by the action of drainage or leaching waters, a relatively small proportion of a component which has entirely passed into the soluble state remaining behind held absorbed by the soil grains. Selective absorption may also play some part, each component passing out at a different rate of speed. The following table of analyses of the drainage water taken from the nine laterals on the tract shows the action of chlorine under leaching.

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[a] Jour. Amer. Chem. Soc., Vol. XXVIII, No. 10, Sept., 1906. See also Cameron and Bell, Bul. 33, Bureau of Soils, U. S. Dept. of Agriculture.

Composition of drainage water from laterals.

	Parts per 100,000.				Proportion in per cents.	
	Na_2CO_3.	$NaHCO_3$.	NaCl.	Total.	$NaHCO_3$.	NaCl.
June 6, 1906.						
Lateral 1	None.	63.60	37.73	104.30	63.9	36.1
2	None.	66.73	48.08	114.81	58.1	41.9
3	None.	66.93	37.73	104.66	63.5	36.5
4	None.	60.45	52.25	122.70	53.7	46.3
5	None.	66.73	18.87	85.60	78.0	22.0
6	None.	70.87	2.17	73.04	97.1	2.9
7	None.	68.81	14.08	82.89	83.1	16.9
8	None.	66.93	20.88	87.81	76.3	23.7
9	None.	45.87	5.08	50.95	90.1	9.9
July 30, 1906.						
Lateral 1	None.	103.47	39.00	142.47	72.6	27.4
2	None	62.14	29.43	91.56	67.9	32.1
3	None.	57.97	21.77	78.74	72.3	27.7
4	Dry.	Dry.	Dry.	Dry.	Dry.	Dry.
5	None.	63.18	15.38	78.56	80.5	19.5
6	None.	59.22	1.88	61.10	97.0	3.0
7	None.	59.22	16.42	75.64	78.3	21.7
8	None.	51.71	14.08	65.79	78.6	21.4
9	None.	31.29	1.88	33.17	94.4	5.6

The analyses of samples taken from June 6, after the pumping had been going on for over two months, show a loss in the proportion of chlorine. In case of lateral No. 6 the chlorine had reached a point at which very little was given up. No change was noticed two months later (July 30). Lateral No. 9 also shows a very decreased amount of chlorine, which was reduced nearly one-half to July 30. In this case the chlorine seems not yet to have reached its lowest stage, which would likely occur when a content similar to that for lateral No. 6 was reached.

In almost exact corroboration of this, Colby[a] found in his analyses of the drainage water from the drainage system at Chino, Cal., that the chlorine content calculated as sodium chloride decreased in proportion to the remaining salts from one-tenth to one one-hundredth of the total salt content in the drainage water. The period covered was four months, and the length of tile 600 feet, very nearly the same length as the laterals from which the observations were taken at Fresno.

These laterals (Nos. 6 and 9) discharged considerably more water than the remainder. The land about them was more nearly free from alkali, and thus had given up its chlorine, none remaining in the solid state. This change in the proportion of components is what might be predicted when one of them no longer remains as a solid in the soil. Similar changes in the drainage water from the whole tract can not be expected until all the surrounding lands have been washed to the same extent as the soils about laterals No. 6 and No. 9.

The concentration of the drainage water at Fresno given in the tables in parts per million varies according to the volume of water passing through the soil. At the end of the season, while the water was running very slowly in the drains and canal, samples from each lateral were taken at the silt boxes, followed several days later by similar samples taken when the water table had dropped below the tiles. The analyses are as follows:

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[a] Calif. Expt. Sta. Rept., 1901-1903

Alkali in drainage from laterals when irrigation had ceased and water was running slowly in the drains.

[Parts per million.]

Date.	Lateral No. 1.	Lateral No. 2.	Lateral No. 3.	Lateral No. 4.	Lateral No. 5.	Lateral No. 6.	Lateral No. 7.	Lateral No. 8.	Lateral No. 9.	Sump.
Sept. 24....	92.4	74.8	74.0	82.0	71.6	72.0	71.2	76.4	10.4	....
Oct. 1......	104.0	108.8	85.6	88.8	117.2	123.6	117.6	....	36.8	74.0

From these results it is seen that the concentration of the salts increases as the water table falls. This is undoubtedly due to the retention of alkali by the soil, which prevents it passing down as fast as the water.

USE OF GROUND WATER FOR IRRIGATION.

The flow of drainage water pumped from the tract was sufficient in quantity to irrigate from 1 to 2 acres daily, but the composition of the salts in this water was such as to preclude its use for irrigation on the white-ash soils. The average of total alkali in solution in the drainage water from the tract for the season was about 100 parts of alkali per 100,000 parts of water. In several other drainage tracts in the Fresno region where drainage has been well established, the alkali in solution ranged from 45 parts per 100,000 to as low as 27 parts per 100,000, the amount of soluble salts usually present in the surface wells of the region. It has frequently been noticed that an increase in the flow of water from drains when flooding is practiced increases correspondingly the alkali content in the drainage water. When no irrigation is practiced on the drainage lands or in the immediate vicinity, the alkali in solution in the drainage waters falls to a comparatively small quantity, at which it remains quite constant. This quantity of salts in solution, when drainage has become efficient and steady, is usually so insignificant that no damage to crops need be feared from its use for irrigation on any of the alkali-free soils at Fresno. Such water may even be effectively used in reclaiming alkali lands from an excess of salts.

The alkali at Fresno is composed mainly of the bicarbonate and chloride of sodium, and a drainage water containing such a combination in quantities greater than 60 or 70 parts per 100,000 should not be applied as irrigation water to any except a very porous and well-drained soil. When such water passes slowly through the soil or remains stationary the alkali is either retained to a considerable extent or partly returns to the soil surface.

A tile filled with alkali-free soil, placed on end in a pan containing 2 inches of this drainage water, within two and one-half days had started a black alkali crust on the surface of the soil 12 inches above the water. A similarly placed soil column treated with pure canal water remained saturated but 4 inches above the water line after three weeks, while the soil treated with drainage water was completely saturated after a few hours, causing a continuous passage of alkali to the soil surface, and increasing the alkali crust until the experiment was stopped. The use of this drainage water on these fields would probably act in a similar manner and in a short time would damage them badly.

Ponds of ground water filling depressions within the body of white-ash lands are usually heavily charged with alkali, and can not with safety be used as a source of irrigation water. Similar ponds in the Fresno sand, a very loose, deep soil, are frequently found near irrigated lands Around Selma these ponds once contained considerable quantities of alkali, but by cutting channels between them[a] the passage of the drainage water through the soil was so greatly increased that their alkali content decreased, and the water can now be safely used for irrigation. Ponds not artificially drained often occur in the Fresno sand. These in many cases are partially drained by underground channels in old stream beds, the movement being sufficient to reduce the alkali content below the danger point. The water in such ponds is often successfully used in irrigation. Ponds of this class containing bicarbonates and chlorides up to 40 parts per 100,000 have been used without injury to irrigate vineyards, peach orchards, and alfalfa on the Fresno sand. With this type of soil, however, the ground water is more than 10 feet below the surface at all seasons. Pumping plants on such soil may be operated without danger of damaging the land from the accumulation of alkali.

EFFECT OF DRAINAGE WATER UPON CANAL WATER.

Some anxiety was felt by irrigators using water below the point on the canal where the drainage water from the tract was added. In order definitely to determine the change in salt content in the canal due to an addition of drainage water samples of the canal water were taken above the inflow of drainage and one-fourth mile below—a point where the waters had become thoroughly mixed. The canal water contained 35 parts per million of soluble salts. After the drainage water had been added to it, the salt content increased to 40 parts per million. The soluble material in both cases was about one-half dissolved silica and the remainder alkali salts. The increase of alkali due to the addition of drainage water is, therefore, so slight that a quantity of such water many times in excess of that now discharged from the drainage system into the canal would be required to render the water of the canal unfit for irrigation.

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[a] Circular No. 50, Office of Expt. Sta., U. S. Dept. of Agr.

As drainage is extended and continued the alkali content of drainage water will become much less, and undoubtedly this water will in time become fit for use in irrigation without an admixture of the pure canal water. The natural drainage water passing downward through the soil and away through natural channels, relieved of the excessive surface and soil water, will carry away much of the alkali washed out of the surface of the soil during the process of irrigation.

During the process of flooding, a certain proportion of soluble inorganic salts known as plant foods was removed from the soil by the drainage water. There was some fear expressed by farmers and others[a] that the amount of plant food removed would seriously impair the fertility of the soil. The canal water used for irrigating the tract and the drainage water removed from it were analyzed for potassium and phosphoric acid to determine the amount of these plant food constituents:

Soluble salts in parts per million.

Sample.	Constituent.			Total.
	PO_4.	K.	SiO_2.	
Irrigation water, Fresno, Cal	4	3	17	35
Drainage water, Fresno, Cal	18	101	20	888
Drainage water, Chino, Cal.[a]	17	6	25	837

[a] Analyses made by Prof. Geo. E. Colby, Cal. Expt. Sta. Rept. 1901-3.

The drainage water from drain at Chino and the drainage from the Toft-Hansen tract carried nearly identical quantities of phosphoric acid. The proportion of potassium was much greater in the latter, but not high enough to cause any uneasiness, because in alkali soils this salt is usually present in excess of the amount generally required for plant growth.

That the concentration for phosphoric acid is nearly constant at a low percentage may have been expected from results in a former publication of this Bureau.[b] This dilute concentration is kept constant by the slight solubility of phosphates,[c] and by the absorptive properties of the soil. There appears, therefore, to be little danger that overmuch plant food will be removed during the process of alkali reclamation.

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[a] Cal. Expt. Sta. Rept. 1901-3, pp. 65 and 83.

[b] Whitney and Cameron, Bul. No. 22, Bureau of Soils, U. S Dept. of Agr.

[c] See Schreiner and Failyer, Bul. No. 32, Bureau of Soils, U. S. Dept. of Agr.

OTHER METHODS OF ALKALI RECLAMATION PRACTICED AT FRESNO.

Besides reclamation by underdrainage and flooding, other methods have been attempted at Fresno. Some of these are as follows: Flushing off the top or surface crust of alkali; breaking holes through the hardpan; working in manure by frequent tillage; tilling constantly during the summer to prevent the rise of alkali by evaporation and capillary movement; applying gypsum as antidote to black alkali; cultivation of alkali resistant plants; and flooding in checks without underdrainage.

USE OF GYPSUM.

Directions have been given by Hilgard[a] for the use of gypsum, to correct the caustic black alkali by changing it to neutral sodium sulphate, which is much less toxic to plants. However, it was noticed that in one spot at Fresno where gypsum had been used much black alkali persisted, even though large quantities of gypsum were added. Quantities of gypsum placed about fruit trees when planted did not prevent them from being killed by black alkali, although plenty of irrigation water was used. It was observed, however, that land treated with gypsum soon shows improved physical condition and will allow the more ready percolation of water. Improved conditions in soils where black alkali continues to exist is due, partly at least, to flocculation of the soil particles caused by the gypsum.

There are many reasons why gypsum fails to effect a permanent reclamation of the black alkali. Among these are its slight solubility, insufficient amounts of gypsum and water used, the reverse reaction to form sodium carbonate, the breaking down of gypsum by living organisms in the soil, and the continued formation of sodium carbonate by reaction of common salt on the hardpan below.

The following table taken from a report by Lapham and Heileman[b] gives the quantity of gypsum necessary to neutralize black alkali in a foot depth of soil by the chemical reaction changing it into sodium sulphate:

Amount of gypsum necessary to correct black alkali.

Per cent of sodium carbonate in soil.	Tons of gypsum necessary to neutralize an acre to a depth of 1 foot.[a]	Per cent of sodium carbonate in soil.	Tons of gypsum necessary to neutralize an acre to a depth of 1 foot.[a]
0.01	0.3	0.20	5.7
.05	1.4	.30	8.5
.10	2.8	.40	11.2

[a] The weight of 1 acre-foot of soil is taken as 3,500,000 pounds.

The average purity of the commercial gypsum used is about 85 per cent, which makes it necessary to add 15 per cent more gypsum than indicated by the above table. According to Means[a] the amount of normal carbonate in the affected district varies from 0.10 to 0.20 per cent. As the bicarbonate is about equal in quantity to the normal carbonate and readily reverts to it enough gypsum must be added in addition to overcome the bicarbonate. With gypsum at $5 per ton it would therefore require from $112 to $228 per acre to entirely convert the black alkali contained in the soil to a depth of 4 feet. Furthermore, it is also well known that gypsum is required in considerable excess over the amount indicated by the theoretical chemical reaction.

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[a] Bul. No. 128, Col. Expt. Sta.

[b] Soil Survey of Hanford Area, California, 1901.

Loughridge[b] found that twice the equivalent quantity of gypsum was necessary to cause a satisfactory decrease in the amount of black alkali, and that the reaction took place in less time than three days. In many places where gypsum was applied it was found after three years only partially dissolved by irrigation or rain. It would therefore be necessary to increase the amount of gypsum greatly above the quantity indicated above.

The amount of water[c] required to render the greater portion of the gypsum soluble to a considerable extent is far in excess of that used in the usual practice of irrigation. The large quantities of water used to reclaim black alkali lands would render the gypsum entirely soluble and this would greatly hasten reclamation by converting the more resistant sodium carbonate to the easily leached sodium sulphate.

Poorly drained soils are filled with quantities of carbon dioxide, which renders calcium carbonate in the soil soluble as calcium bicarbonate. Calcium bicarbonate reacts with sodium chloride to form sodium bicarbonate, which on loss of carbon dioxide forms the normal sodium carbonate. This process replaces the sodium carbonate removed from soil by the reaction with gypsum. The more rapid and complete the action of gypsum on black alkali the more rapid is the reaction of sodium chloride and calcium bicarbonate to supply the depleted sodium carbonate.

Bacteria tend to destroy the effect of gypsum by breaking it down with the formation of hydrogen sulphide, which escapes into the air.[d] In water-logged or swampy lands in poorly drained alkali areas gypsum is attacked by the thio-bacteria, *Beggatoria alba*.[e]

This condition, resulting in the breaking down of the sulphates, was noticed while draining the tract. Before the tiles began to run properly and the water remained stagnant in the soil, a strong odor of hydrogen sulphide was detected in the sump and silt boxes. As soon as the drains began to run properly, this odor entirely disappeared and did not return.

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[a] Soil Survey Around Fresno, Cal., 1900.

[b] California Expt. Sta. Report, 1895–96, p. 40.

[c] For solubility of gypsum in water and solutions see Bul. No. 33, Bureau of Soils.

[d] Schreiner and Failyer, Bul. No. 31, p. 51, Bureau of Soils.

[e] Ibid.

Finally, it must be remembered that, while the toxicity of the alkali is greatly reduced, the quantity is actually increased by the resulting sodium sulphate.

CONSTANT TILLAGE.

In the vineyards and orchards at Fresno constant tillage is practiced during the growing season to prevent the rise of alkali which has been washed down during the winter by rain. Vines and trees are greatly invigorated by this extra culture, which enables them better to withstand the inroads of alkali. This practice, however, will not prevent the ultimate ruin of the orchards where the water table is close to the surface.

INCORPORATING BARNYARD MANURE.

Plowing quantities of barnyard manure into alkali land has been found greatly to improve heavy soils which contain a small amount of injurious alkali. This method coupled with frequent cultivation appears to have overcome entirely the effect of alkali. This is due not to the removal of alkali, which is present in even greater amounts by addition of that contained in the manure, but to the scattering of the alkali evenly through the soil. At the same time the capillary movement, which would soon concentrate the alkali at the surface, is checked. Moisture is likewise conserved by the extra tilth and added organic matter. This is a favorite and successful method with Italian and Chinese gardeners.

BLASTING HARDPAN.

Breaking holes through the hardpan to the underlying water-carrying sands by digging or dynamiting has given poor results for the outlay of time and money. The water table is too close to the surface and is usually above the hardpan during the growing season, thus preventing the drainage of alkali water down into the lower strata. An attempt was made to reclaim an alkali spot on the Toft-Hansen tract by blasting the hardpan during early summer, but it proved a failure, for the hardpan was so tough that no cracking occurred and only small holes were opened, which soon filled, and becoming puddled were almost as impervious as before. Blasting during the dry season of the year would probably have shattered the hardpan to a greater extent.

SURFACE FLUSHING.

Flushing, or washing off the surface by running water, is usually efficient in removing most of the surface alkali, but it must be repeated continually. Fields are often greatly improved by this method, and it is also a most valuable adjunct in reclamation by underdrainage, removing quickly most of the crust or surface salts. On a portion of the Toft-Hansen tract where hardpan existed within 2 feet of the surface flushing was practiced by passing the water over the land into the drainage system. Every two or three days this surface flushing was repeated. At the end of five or six weeks half of the alkali was removed. The following table shows the rate at which alkali went into solution:

Rate of solution of alkali near the surface of the soil.

[Parts per 100,000.]

Hours.	Na_2CO_3.	$NaHCO_3$.	NaCl.	Total.	Notes.
0	0	1.85	1.74	3.59	Canal water June 15.
½	....	10.40	4.16	14.56	
3	....	13.75	5.80	19.55	
20	....	20.86	7.54	28.40	
48	Trace.	23.36	9.28	32.64	Drained and evaporated to one-third.
96	7.56	17.48	9.28	34.32	Evaporated almost to dryness.

The analyses in this table show that practically all the alkali at the surface of the soil goes into solution in two days. A great proportion of it was found in solution after three hours. This shows that a period of time varying from three to twenty-four hours would be sufficient to dissolve the greater part of the surface alkali, and that it would even be practicable to inclose lands containing crusts of alkali on the surface of the soil in large checks and keep a continual stream of water passing over it until the concentrated alkali near the surface was largely removed. Flushing the surface as an aid in cleaning lands from alkali can be successfully used only at the beginning of the flooding.

FLOODING WITHOUT UNDERDRAINAGE.

Flooding land in checks to wash down alkali is the oldest method and the one most often practiced in the reclamation of alkali lands. It has been used successfully in many places in the San Joaquin Valley, where the soil is well drained and free from impervious layers of hardpan. At Bakersfield many bad alkali tracts have been successfully and permanently reclaimed by this method. Most of this land is a loose sandy loam or sand for the first 2 or 3 feet, which enables the water to percolate freely. Water 1 foot deep is held over this soil during the spring or irrigating season until May or June. The land is then planted to Egyptian corn, the shade of which retards the capillary rise of alkali. During the next fall or following spring the land is seeded to alfalfa and given as heavy flooding as possible at the usual time for irrigation.

The following table by Loughridge[a] gives the amounts of alkali before and after flooding on an alkali spot near Bakersfield:

Quantity of alkali in soil before and after flooding.

	Per cent Na_2SO_4 in soil.	Per cent Na_2CO_3 in soil.	Per cent NaCl in soil.	Total salts in soil.	Per cent total leached out.
Before flooding	0.385	0.004	1.127	1.580	....
After flooding and with good stand of alfalfa	.092	None.	.007	.119	93.7

No hardpan existed in this soil, and the ground water fluctuated between 10 and 16 feet below the surface of the soil.

At Fresno this method has been tried in many places. Near the Toft-Hansen tract a field was successfully reclaimed from alkali in this manner and produced good barley and alfalfa. In changing owners the policy of repeated deep flooding was discontinued, the result being that in the course of a season or two the alkali came to the surface and ruined the land. The success of flooding alone, i. e., without artificial underdrainage, at Fresno depends largely upon the variations of the water table.

RECOMMENDATIONS FOR RECLAIMING LANDS AT FRESNO.

From the experience of the Bureau of Soils in reclaiming the Toft-Hansen tract, the following recommendations are given for those contemplating similar work:

As hardpan of irregular contour is present at varying depths in most Fresno alkali soils, the first work should be to map the depth of this formation. This is readily done by the use of a 6-foot soil auger. Hardpan below 6 feet is not dangerous. This boring gives the depth of the soil and its texture and shows where the lines of tile may be placed to avoid digging through excessive depth of hardpan. The channels and depressions in the hardpan can thus be taken advantage of, as well as the natural fall of the country drainage, and the distance between the tile mains and laterals can be determined to the best advantage. Main lines of tile one-fourth mile apart appear to be sufficient in the Fresno sand or the Fresno sandy loam, when supplemented by additional laterals to spots retaining alkali in excessive amounts. Drainage flows from the entire district have been discussed by Elliott.[b]

In planning a small drainage system the most serious concern is an outlet for the drainage water. At Fresno there are two possible methods for carrying away drainage water—gravity and pumping.

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[a] California Expt. Sta. Report.

[b] Office of Expt. Sta., U. S. Dept. of Agr., Drainage Investigations, 1903.

As the fall of the country is 5 feet to the mile or less, in order to secure a gravity outlet 7 or 8 feet deep it would be necessary that the ditch be dug into Fresno slough 15 miles from the area affected. Power for pumping may be obtained by using gasoline, electricity, or water. The latter power is afforded by the large canals of the district, and was used in the Toft-Hansen tract experiment and by several other drained farms at Fresno. A water wheel of sufficient power to lift the drainage water from 250 to 300 acres costs about $250. Aside from accidents, the cost of running the water wheel pump or lift is low. The gasoline engine is, of course, more expensive, but can be operated at any time. The electric power pump is far easier to manipulate and requires little care. Electric power promises to be cheap and available for this work in the near future.

The silting of tiles has proved serious, not only in the arid lands of the United States, but also in India[a] and elsewhere. Tiles should be fitted together as closely as possible, for otherwise sufficient silt enters to fill them, especially in micaceous sandy and silty loams. In heavy loams, cohesive sandy loams, clays, and adobes silting does not occur to any appreciable extent. Attempts to prevent silt from entering the tiles by placing hay or tarred paper over the joints have not been effective. The manner in which this difficulty has been overcome on the Toft-Hansen tract has already been described.

The roots of fig, elm, eucalyptus, willow, poplar, cottonwood, and maple trees may be cut out of tiles quite readily with the steel wire brushes, which also have been described in this paper, if the trees are not closer than 30 feet. Vines may be planted much nearer, and alfalfa does not enter unless the tiles already contain large quantities of silt.

The cost of installing a drainage system at Fresno comes under three heads, namely, cost of tiles, expense of laying them in the ground, and expense of providing an outlet for the drainage water. No attempt will be made to give the cost of a drainage outlet, for this item varies for each farm. The cost of the first item, tiles, varies from year to year, but as there is now a local supply large orders of tiles should be obtainable at comparatively low prices. The prevailing prices on small lots during 1905 were for 4-inch, $32; for 6-inch $72, and for 8-inch $120 per thousand feet f. o. b. at Fresno. The second item of expense—laying the tiles—was 5 cents per linear foot for tiles placed in the ground at a depth varying from 5 to 7 feet.[b] Along the lines of mains and along laterals of great length boxes should be placed 18 inches below the tiles at intervals of 300 feet to serve as silt basins. If redwood lumber is used in making them, it should be at least 1½ inches thick, as thinner boards warp and allow earth to enter between the cracks. A good box for this purpose is about 6 feet long and 2½ feet wide, inclosed with a close-fitting cover. In the drains between these boxes a cable should be laid, with a windlass at each end to pull the cleaning brushes back and forth. Such windlasses cost about $7.50 each, the wire brushes $6 each, and the 7-strand quarter-inch galvanized steel wire cable about $8 per 1,000 feet.

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[a] Annual Report, Imp. Dept. of Agr., India, 1904.

[b] For a complete description of the methods of surveying drains and laying the tiles in place, see Drainage of Farm Lands, Farmers' Bulletin No. 187, U. S. Dept. of Agr., and Engineering and Drainage, both by C. G. Elliott. These publications give the simplest and most effective methods in use by farmers.

The cost of leveling and checking ranges between $5 and $30 an acre. On many farms in the alkali district southwest of Fresno the land has already been leveled and ditched for irrigation by flooding. The cost of reclaiming these lands may be estimated to be between $10 and $30 an acre, not including the expense of labor in applying the water and cleaning the tiles.

The best time to flood is during the winter when evaporation and the capillary rise of alkali are slight. Evaporation during the winter months decreases to one-fifth of that during the summer months. The ground water at this time is also very low, enabling the water carrying the alkali to pass deeply into the soil. This flooding may be done by pumping water on the land from wells before the canals begin to run. Afterwards canal water can be applied more cheaply.

DEPTH OF FLOOD WATER.

In order to remove sodium carbonate a good depth of water over the soil is necessary. A depth of water from 1 to 4 inches is not sufficient on the white-ash lands to convert carbonates completely or to drive down alkali, but may be sufficient on sandy soils.

For several reasons a much larger quantity of water than is necessary to dissolve the salts must be used to remove alkali successfully. Water passes downward through the larger spaces, leaving almost undisturbed the alkali in the more compact soils. Each soil grain holds absorbed on its surface a part of the dissolved salts. Most fields are of uneven texture and allow water to percolate more rapidly in some places than in others.

The rate of passage of alkali salt under various depths of water is given in the following table:

Rate of leaching out alkali from soil by flooding.

Stake number.	Depth.	Na_2CO_3 in soil.		$NaHCO_3$ in soil.		NaCl in soil.		Total salt in soil.		Maximum depth of water over soil.	Duration of flooding.	Proportion leached out.	
		Before flooding.	After flooding.	Before flooding.	After flooding.	Before flooding.	After flooding.	Before flooding.	After flooding.			Gain.	Loss.
	Feet.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Inches.*	*Days.*	*P. ct.*	*P. ct.*
I	1	0.293	0.019	0.048	0.067	0.125	0.020	0.466	0.106	3	35	......	67.3
	2	.090	.024	.066	.072	.067	.033	.223	.129			......	42.2
	3	.090	.016	.072	.084	.092	.033	.254	.133			......	47.6
II	1	.291	.106	.108	.084	.609	.033	1.008	.223	2	35	......	77.8
	2	.098	.098	.096	.078	.092	.042	.286	.218			......	23.8
	3	.098	.089	.096	.060	.092	.058	.286	.207			......	47.2
III	1	.293	.057	.126	.084	.701	.033	1.120	.174	3	35	......	84.5
	2	.065	.049	.088	.060	.133	.042	.286	.151			......	47.2
	3	.093	.057	.004	.072	.100	.109	.197	.229			16.2	....
IV	1	.163	.065	.114	.108	.134	.033	.411	.206	2	28	......	49.9
	2	.098	.054	.018	.065	.159	.192	.275	.311			13.0	....
	2½	.098	Trace.	.018	.096	.159	.200	.275	.296			7.6	....
V	1	.198	None.	.048	.050	.083	.042	.229	.092	10	35	......	59.9
	2	.090	None.	.096	.054	.042	.038	.228	.092			......	59.7
	3	.106	None.	.102	.048	.058	.033	.266	.081			......	69.6
VI	1	.196	.015	.048	.097	.451	.134	.695	.246	4	21	......	66.2
	2	.049	.065	.120	.030	.033	.167	.185	.218			18.2	....
VII	1	.098	None.	.048	.036	.083	.027	.229	.063	12	42	......	27.5
	2	.090	None.	.096	.048	.042	.026	.228	.074			......	68.5
	3	.106	None.	.102	.048	.058	.026	.226	.074			......	....
VIII	1	.416	.008	.180	.090	.157	.021	.755	.119	4	28	......	84.3
	2	.130	.016	.228	.066	.083	.033	.441	.115			......	74.0
	3	.065	.033	.108	.078	.058	.033	.231	.144			......	37.7
	4	.033	.033	.074	.132	.050	.065	.157	.230			46.5	....

It will be seen from the above table that where the maximum depth of standing water was close to 10 or 12 inches the total alkali content was reduced below 0.1 per cent and the sodium carbonate entirely converted into bicarbonate. Where this depth of water was used no carbonate again appeared even after two months' summer exposure.

Where a good depth of water was held continually over the soil, five or six weeks' time was sufficient to remove the alkali below the danger limit. Where the soil was heavier in texture more time and a greater depth of water secured the same results. It is not at present advisable to attempt to reclaim lands where hardpan approaches close to the surface, for the depth of soil is too shallow for trees, vines, or alfalfa.

When flooding is practiced in the neighborhood of a dwelling, fresh-water algæ often accumulate, causing offensive odors and unsightly green scum. On the tract at Fresno this was overcome within four or five hours by placing bluestone (copper sulphate) in the water as it ran into the checks of standing water. One part of bluestone (copper sulphate) to 100,000 parts of water is sufficient to secure these results, and the cost is slight.[a]

Evaporation losses are considerable, especially during summer flooding; the daily evaporation on the tract during the month of June was found to be 0.285 inch, making a total of 8.55 inches for the month. The monthly evaporation in the arid parts of California varies from 5 to 9 inches, according to studies made by Lee[a] and Fortier.[b]

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[a] Bul. No. 64, Bureau of Plant Industry, U. S. Dept. of Agr.

Flooding for one season will usually be found sufficient to reclaim all except the most strongly impregnated alkali soils. Occasional deep flooding in succeeding years will keep them free from injurious quantities of alkali.

FLOODING VINEYARDS IN ALKALI SOILS.

Where established vineyards are affected with injurious quantities of alkali, flooding to a depth of 1 foot may be continued without injury from December to March, when the vines are ready to sprout. Flooding in vineyards may be practiced during hot weather if care be exercised to prevent sun scald. Alfalfa and trees are more easily injured by standing water than are vines.

In order to determine when the alkali content is reduced below the danger point for vines, it is necessary either to make chemical analyses or to test the soil by practical observation. The following field method may be quite definitely relied upon in the white-ash soils in the vicinity of Fresno to determine the limit below which vines are free from alkali injury: Dig a trench 3 feet deep, 18 inches wide, and 10 feet long from west to east. Allow the sun to shine into it for three or four days. If a dense black discoloration characteristic of black alkali and thickly interspersed with salt crystals plainly appears on the sun-exposed north side of the trench, there is still too much alkali in the soil. If, however, only a brown irregular discoloration and few crystals of salts appear interspersed with streaks of natural-colored soil, the land is free enough for alfalfa and grain; but if no discoloration except that natural to damp soil full of organic matter be present, then vines or any other sensitive plants, such as sweet potatoes, peanuts, etc., may be planted with entire safety. Instead of the cemented and puddled condition the reclaimed soils become loamy and friable.

SUMMARY.

In summing up the results obtained by the alkali reclamation experiments of the Bureau of Soils on the Toft-Hansen tract at Fresno, the attention of those owning farms ruined by alkali is again drawn to previous statements of the Bureau of Soils, advising underdrainage and flooding as a remedy for the alkali soil.[c] This method of treating alkali lands has proved a sure and efficient remedy at a cost well within the means of ordinary farmers and but a fraction of the value of the land. A great deal of valuable experience has been gained and is now available to those reclaiming alkali lands.

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[a] Geology and Water Resources of Owens Valley, California, Water-Supply and Irrigation Paper No. 181, U. S. Geol. Survey.

[b] Circular No. 59, Office of Expt. Sta., U. S. Dept. of Agr.

[c] Survey Around Fresno, 1900, Bureau of Soils, U. S. Dept. of Agr.

It has been found that alkali can be washed out of these white-ash soils, where no hardpan occurs close to the surface, during one irrigating season. It should then be fit to produce paying crops.

The alkali at Fresno in the white-ash soils consists mainly of black alkali. To remove this alkali rapidly and effectively, it has been found necessary to hold water continually for several months over the soil at a depth of about 1 foot. When this is done, black alkali need not be feared.

The amount of tiling necessary to drain these alkali lands for reclamation has been determined to be far less than formerly thought necessary. Natural stream channels and the great porosity of these soils made it possible to place drains several hundred feet apart, thus materially reducing the cost of reclamation.

Efficient drainage systems, together with pumps of small capacity, have been found to remove easily and permanently a sufficient quantity of ground water to keep the water table below the danger limit throughout the irrigating season. These pumps may be readily driven by power furnished by water wheels in the canals. Cheap electricity also soon promises to be available for this purpose where water power is not to be had.

When installing drainage systems, a competent engineer should be employed in order that the drains may be correctly laid on a proper and uniform grade. A contour survey of the surface of the land, together with one of the hardpan, is necessary to avoid the heavy cost of digging through hardpan and at the same time to secure the best drainage.

In placing the tiles in the trench great care should be taken to crowd them closely together to exclude silt and sand. Silting is a serious problem in many alkali soils, but may be overcome readily by placing cables in the drains and drawing brushes through them.

The time necessary to drive alkali out of the freer soils by continuous deep flooding may be as short as six weeks. Heavier soils require more time, but usually not more water.

The practical trench test, to determine when the alkali has been sufficiently removed and when flooding should cease, should be used. A grain crop should follow during the next winter season. Any spots showing alkali can then be readily detected and treated in the following spring and summer.

With the experience gained by the Bureau of Soils as a guide no insurmountable difficulty in freeing land from alkali should be encountered by farmers. The success attained in draining individual farms at the Toft-Hansen tract and other places clearly demonstrates that such drainage is a permanent and financial success. That such individual work will in time solve the problem of alkali reclamation seems highly probable.

APPENDIX.

PLANTS USED AS ALKALI LAND INDICATORS.

The following list of plants more or less resistant to alkali, with a discussion of their relation to alkali conditions in the soil in the Fresno district, is given to assist farmers and others interested in determining the conditions in any given case. In other Western States, and even in other parts of California, the resistance of the same plants may be quite different. In the absence of exact information, such as that afforded by chemical analyses, the value of plants as indicators of alkali is unquestioned. Thus on lands which have not yet been irrigated and planted to crops there are found growing many native plants which thrive best under certain conditions of alkali and in soils of certain depth and texture. While these plants are not always infallible indicators of these conditions, they may in the majority of instances correctly guide the farmer in selecting or rejecting new or hitherto undeveloped lands. In this manner serious mistakes and waste of capital may often be averted.

For identification of alkali lands in the field the following native plants are often successfully used:

Saltwort or inkweed (*Suæda* sp.).
Kern County greasewood (*Allenrolfea occidentalis*).
Saltbush (*Atriplex* spp.).
Alkali heath (*Frankenia grandiflora campestris*).
Little rabbit brush (*Bigelovia veneta*).
Alkali weed (*Centromedia pungens*).
Arrow or irrigation weed (*Pluchea sericea*).
Salt grass (*Distichlis spicata*).
Foxtail or barley grass (*Hordeum murinum*).
Slender water or alkali grass (*Leptochloa imbricata*).

In discussing these plants the depth and texture of the soil upon which they grow, the amount and kind of alkali (black or white) tolerated by them, and the possibilities for drainage and alkali reclamation are given. The three different grades of alkali—lower, medium or moderate, and heavier—are represented by 0.10 to 0.30, 0.30 to 0.50, and above 0.50 per cent in the soil.

Inkweed, or salt bush, is a perennial shrub with a small, fleshy, stemlike leaf. Each winter the plant dies down close to the ground, leaving behind a dark-colored brush. This plant grows only in badly alkaline soils, usually with high black alkali content and with a heavy sandy loam or clay loam texture. No crop has been found growing on the land covered by this plant. The soil usually occupies a depression in which alkali has accumulated and puddled the soil, holding rain or irrigation water above it until evaporated. Where the inkweed grows on elevated soils, there has usually been found hardpan close to the surface. Such land has not been profitably reclaimed from alkali.

Kern greasewood is an evergreen bush 2 to 4 feet in height, with short stemlike fleshy leaves. It grows only on soils containing a large quantity of black alkali. It is found in the lower soils in the valley trough, where they are heavy in texture and receive and retain considerable moisture. Such soils have not been found to produce crops, and it is doubtful if the reclamation of such lands can be made profitable unless crops hitherto untried can be found to grow on them.

Saltbush never grows except when alkali is present in the soil. Two sorts are found—the bush or perennial and the weed or annual. The perennial saltbush is an ashen-gray colored bush, usually mistaken for sage brush. It can be readily detected by its seeds, which closely resemble those of the beet. It belongs, in fact, to another genus of the same family. Although this saltbush will grow in soils containing considerable black alkali, it prefers the white alkali—sodium chloride and sodium sulphate. Soils growing this bush are usually sandy loams for about 3 feet, underlain by heavier soil, in which the body of the alkali occurs. This land contains, as a rule, no hardpan or close water table and can be readily reclaimed by simply flooding to a considerable depth while irrigating crops. Shallow flooding or only surface wetting of such lands will soon carry the alkali to the surface in the form of a white crust.

Weed, or annual, atriplexes are sure indicators of alkali, but do not determine the kind, as they do equally well on soils affected with white or black. These weeds grow luxuriantly in free soils, usually of a sandy loam texture. These weeds are grayish green with a scurfy covering, the dust of which is very irritating to the nose. In height they range from 1½ to 4 feet. They indicate in most cases the lower limit of alkali (from 0.10 to 0.30 per cent) and it is usually found below the first or second foot of soil. Where these weeds do not occur over hardpan close to the surface, the land has been found to produce good barley and alfalfa and even vineyards and peach orchards. It should be handled very carefully in order to avoid capillary deposits of alkali in the surface from the accumulations usually found below. These lands yield readily to alkali reclamation by flooding and drainage.

Alkali heath is a perennial herb growing to a height varying from 1 to 2½ feet. This brush indicates the lower limits of alkali (0.10 to 0.30 per cent), and is found bordering large bodies of lands badly affected with either white or black alkali. Where this bush is found growing uniformly over an area to the exclusion of the more resistant alkali indicators, the alkali is found below the surface from 1 to 3 feet in a free sand or sandy loam soil. This land yields crops of alfalfa and grain or orchards and can be kept free from injurious quantities of alkali by proper methods of irrigation and drainage.

Little rabbit brush is a perennial composite bush about 18 inches high, with a sparse, smooth dark-green foliage. It grows in deep soils of a loamy texture with alkali in medium grades (0.30 to 0.50 per cent) or lower limits (0.10 to 0.30 per cent), usually sulphates. Such lands will admit of easy reclamation and should be very productive with proper irrigation.

Alkali weed, a yellow-flowered spiny-leaved composite, grows in a dense mass to a height varying from 2 to 8 feet, usually to the exclusion of other vegetation. It grows in either black or white alkali land in the lower (0.10 to 0.30) or medium (0.30 to 0.50) limits for alkali. It grows on sandy, sandy loam, and adobe soil equally well. It does not do well in soil with hardpan too close to the surface and prefers a soil with fair drainage. Where this weed grows grain crops are very spotted and are usually unprofitable. Alfalfa also does but poorly. It is unfit for vines and trees unless drained and the alkali removed.

Arrow, or irrigation, weed is a composite which grows in a single long straight stem 4 to 8 feet high with a brushlike head of leaves and flowers. It grows only in the lower alkali limits (0.10 to 0.30 per cent) in porous soils, generally after irrigation, and indicates a soil in which the alkali is not dangerous and may be gradually disappearing under irrigation connected with the naturally good drainage. The soils growing this weed are porous, deep, and generally well drained.

Salt grass is a short harsh grass very common in alkali lands. It will grow on all grades of soil and alkali, but does best in very salty soils above 0.50 per cent. Soils free from alkali are often found covered with it. It is thus a poor indicator of alkali conditions.

Foxtail, or barley grass, grows in considerable amount of alkali, or up to 0.50 per cent, because it sprouts and grows during the winter when alkali is not as harmful as in summer. Where foxtail grows well the soil is usually deep and rich and can be made to grow other crops profitably.

Slender water grass, or alkali grass, grows well during the summer season wherever water is allowed to stand for a time over alkali land, even with considerable amounts of black alkali present. This is the most nutritious native alkali-resistant plant at Fresno. It reseeds or plants itself without other culture or care than plowing and flooding in spring or summer. In reclaiming alkali soils by flooding, this grass gives considerable feed, both green and dry.

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 43.

MILTON WHITNEY, Chief.

RECLAMATION OF ALKALI LAND IN SALT LAKE VALLEY, UTAH

BY

CLARENCE W. DORSEY.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., April 30, 1907.

SIR: I have the honor to transmit herewith the manuscript of a report entitled Reclamation of Alkali Land in Salt Lake Valley, Utah, and to recommend that it be published as Bulletin No. 43 of this Bureau.

Very respectfully,

MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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RECLAMATION OF ALKALI LAND IN SALT LAKE VALLEY, UTAH.

INTRODUCTION.

Sixty years after the hardy Mormon pioneers made their appearance in Salt Lake Valley there yet remains an extensive body of land, extending westward from the Jordan River to the shores of Great Salt Lake, that contributes but little to the agricultural importance of Utah. At first it appears strange that such extensive tracts of level land should remain undeveloped with Salt Lake City close at hand offering perhaps the best market to be found in the West for all classes of farm produce. On the east side of the valley, situated the same distance from Salt Lake City, farm land finds a ready sale at prices of more than $200, and even $300, an acre, and produces plentiful crops of great variety. It was in this part of the valley that irrigation was first practiced in Utah. The crude beginning is described by Mr. E. G. Wooley, a bishop in the Mormon Church, in the following words: "The pioneers came into the valley in July, 1847. The advance company drifted right down upon the site of Salt Lake City. They went to work the first day, ran a plowed ditch out of City Creek, and started the water out on the ground and planted some potatoes the same day."

The reason for the backward development of the large body of land between the river and Great Salt Lake lies in the fact that the soils contain soluble salts in such quantities that useful crops can not be grown. Once the salt or alkali is removed the soils will be found as rich as those which enabled the industrious pioneers to prosper in the manner they have done. That reclaiming these soils is not only possible but practicable will be shown in the following pages by describing the reclamation of one of the most strongly impregnated tracts of alkali land found in the valley. After detailing the work on this tract the practical application of this experimental work to the damaged lands of the valley will be shown; that is, we will consider just what steps the farmer must take to make productive the extensive areas of alkali waste land.

DESCRIPTION OF SALT LAKE VALLEY.

Salt Lake Valley lies in northern-central Utah and comprises the greater part of the western half of Salt Lake County. The valley attains a maximum width of something more than 20 miles from east to west and a somewhat greater length from north to south. The valley is characterized by wide stretches of comparatively level land, sloping gently to the north and west, and by a number of slight ridges that rise only a few feet above the general valley floor. On the margins of the valley the ridges are more pronounced. Salt Lake City, 14 miles east of Great Salt Lake, has an elevation of 4,253 feet. The Wasatch Range rises abruptly above the valley on the east, and many peaks attain an elevation of over 11,000 feet. To the south the valley gradually converges into the Jordan Narrows. On the southwest the Oquirrh Mountains rise 3,000 to 4,000 feet above the valley floor. Bordering the valley on the north and west occurs Great Salt Lake, a shallow body of water covering an area of about 2,000 square miles. Great Salt Lake constitutes only a remnant of a former lake that once attained an area of nearly 20,000 square miles. This prehistoric body of water, named Lake Bonneville in honor of the intrepid explorer, at one time stood 1,000 feet higher than the present lake level. Evidences of the former lake are everywhere visible, even to the untrained observer, in the many pronounced shore lines that stand out in bold relief hundreds of feet above the present valley floor. The Lake Bonneville basin, together with many inclosed drainage basins in Nevada, Oregon, and California, broken by parallel ranges of mountains, constitutes the physiographic region known as the Great Basin, the character and extent of which was first made known by the explorations of Fremont.[a]

Salt Lake Valley, in common with other extensive interior valleys, has what may be termed a true continental climate, relieved to some extent by the modifying influence of Great Salt Lake.[b] Temperatures at Salt Lake City range from −20° F., the lowest recorded minimum, to 102° F., the highest recorded maximum, with 52° as the annual mean temperature. The precipitation during the period 1874 to 1903 for the driest year was 10.2 inches and for the wettest year 23.5 inches, with 15.8 inches representing the average rainfall for the period. The spring months, March, April, and May, receive the greatest rainfall, with an average of nearly 2 inches each month. The summer months receive the least rainfall, the entire three months receiving only 2 inches of rain. The average depth of snow for the year is slightly more than 50 inches. The relative humidity is low, especially during the summer months, at which time the percentage of possible sunshine is the highest of the year. These conditions of light rainfall, low relative humidity, and high temperatures hasten evaporation during the summer months, making irrigation necessary to insure the best results. Dry farming is possible only for such crops as mature before the hot summer sets in and is practiced but little in the valley proper. Considerable dry farming is carried on in the valleys of the lower foothills and on the higher bench lands, where the rainfall is appreciably greater.

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[a] Lake Bonneville, Monograph of U. S. Geol. Survey, by G. K. Gilbert, 1890.

[b] Bul. Q, U. S. Weather Bureau, 1906.

SOIL AND ALKALI CONDITIONS IN SALT LAKE VALLEY.

In 1899 the Bureau (then Division) of Soils, in cooperation with the Utah experiment station, made a soil survey of that portion of the valley lying west of Jordan River. This survey comprised an area of over 250 square miles, but did not include the best farming districts of the valley lying east of the Jordan River. This should be remembered in the discussion of the alkali problems, since the lands east of the river are but little affected by alkali. There are some alkali areas south of Salt Lake City, especially in the bottom along the river, but the greater extent of land east of the river has good slope, which implies fair natural drainage with the tendency for the salts originally contained in the soils to be washed to lower levels. It is this part of the valley that has had the greatest agricultural development and is at present in a prosperous condition.

This soil survey was made by Frank D. Gardner and John Stewart, and the report was published in the Field Operations of the Division of Soils, 1899, and as Bulletin 72 of the Utah experiment station. The soils were found to have been formed by material brought down from the mountains and from sediments of ancient Lake Bonneville, all of which have been materially modified by inflowing streams from the mountains and by the advance and recession of Great Salt Lake. On account of the manner of their formation the soils vary greatly in character. In the lower part of the valley the lacustrine deposits are very deep, no rock or gravel being found at a depth of a hundred or more feet. As we approach the foothills gravel and rock are plentiful and often crop out at the surface, and the depth of lake sediments diminishes and in many places none at all is found.

The soils are fertile, but in their natural condition support only a meager vegetation, because they are either too dry or contain too much alkali. On the higher levels, where little salt is present, sagebrush forms the chief growth, while in the lower parts of the valley, where there is more moisture and much salt, greasewood, salt grass, and other salt-loving vegetation forms the principal growth.

The most important soil type was found to be the Jordan sandy loam, a light-colored sandy loam, with a depth of several feet, overlying clay. Where this class of soil is above irrigation canals and in the irrigated districts wherever the subsoil water is 10 feet or more below the surface it is generally free from excessive quantities of alkali. In the low areas, especially in the northern part of the valley, there is much alkali in the lower depths of soil. This soil is easily cultivated and where free from alkali is a desirable soil for any crops grown in the valley.

On the higher slopes of the southern part of the valley occur extensive areas of a gravelly loam soil. This soil is usually free from alkali, but on account of the large amount of gravel and high position is difficult to irrigate. Much of this soil is dry-farmed to wheat with good results in years of abundant rainfall.

Another important type of soil was found to be the Jordan loam. It comprises an area of about 50 square miles, most of which is below the present canal systems. It is a heavy loam overlying a clay subsoil. Where free from alkali and under cultivation the Jordan loam is an excellent soil, but the water table is generally within a few feet from the surface and the alkali content is considerable in the lower depths of soil.

The Jordan clay occupies about 35 square miles, occurring largely in low positions, usually from 4 to 8 feet below the land immediately adjoining. It is level and wet and rarely supports any vegetation. It represents what was formerly the floors of lagoons near the shore of the lake, and in many places it is now the floor of draws extending like wide irregular canals back into the land for miles. On account of the clayey nature of this soil, the low undrained position, and high alkali content it is at present not suited to agricultural purposes. Other less important classes of soils were found that need not be considered.

In a number of small areas hardpan was found, occurring principally in connection with the sandy loam soils. The hardpan usually is encountered at an average depth of 18 inches and ranges in thickness from 2 to 18 inches. It is composed of material similar to that immediately above and below it, cemented by lime carbonate. When dry this hardpan is hard and difficult to penetrate, but after irrigation has been practiced for some time it readily softens and is pervious to water and the roots of plants. Usually it was observed that the soil above the hardpan was free from alkali, while below the hardpan the salt content was much greater.

The main water supply for the western part of the valley is derived directly from Utah Lake, a large body of fresh water lying south of Salt Lake Valley. It has an area of approximately 125 square miles but is rather shallow. It is fed largely by short mountain streams derived from melting snow. While the inflowing streams contain but little soluble salts seepage from surrounding lands affects the salt content of the lake. The outlet of Utah Lake is the Jordan River, from which several canals are taken out. While the salt content of the Jordan varies at different points, depending to some extent on the amount of seepage water it receives from irrigated land, it is usually of good quality. Analyses of the water from Jordan River at the time the survey was made, 1899, showed the presence of from 80 to 110 parts per 100,000, consisting mainly of the chlorides and sulphates of sodium and calcium.

The distribution of the alkali was found to depend largely upon the topography of the valley as well as upon the character of soils. The accompanying sketch map (fig. 1) shows the extent of lands containing more than 0.60 per cent of alkali. As a rule the greatest accumulations of alkali were found in the heavier textured soils that occupy the lower portions of the valley. The heavy clay soils that have within recent years been covered by Great Salt Lake almost without exception contain excessive quantities of alkali. In these areas also the water table stands within a few feet of the surface. The heavy nature of the soil, the shallow ground water, and the low position have caused these soils to retain the salts added by contact with the saline waters of the lake. On the higher ridges in the valley and on the more sloping lands bordering the valley the ordinary precipitation in the form of rain or snow has leached away considerable of the salts orignally contained.

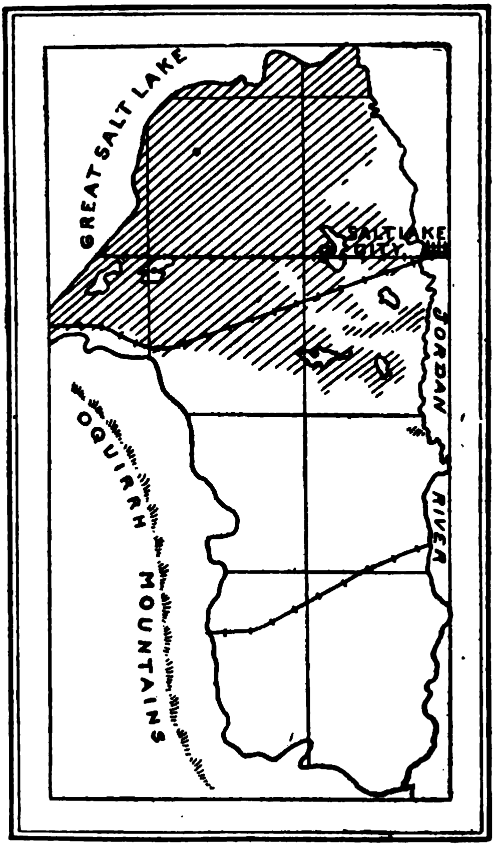

FIG. 1.—Sketch map showing distribution of alkali in Salt Lake Valley. Hatch lines cover area affected.

It was found that the character of the soil and the depth to standing water were the most important factors in determining the vertical distribution of alkali in the soil. On sandy soils with the water table several feet below the surface the top soil was generally free from alkali, but it increased in amount in the lower depths. Where the water stood within 3 feet or less from the surface the greater part of the alkali was concentrated at or near the surface.

The source of the alkali is probably the waters of Great Salt Lake (which within the memory of the older inhabitants has covered much of the low-lying lands) or in the case of the more elevated lands the waters of Lake Bonneville. The alkali is largely composed of sodium chloride with a smaller quantity of sodium sulphate and a small percentage of the chlorides, sulphates, and carbonates of calcium and magnesium. Sodium carbonate, black alkali, is often found, generally in small quantities.

During the progress of the survey in 1899 it was found that an area of more than 77,000 acres was practically free from alkali. This large area comprises the more sloping lands where good natural drainage and porous soils have prevented injurious accumulations of alkali. Seventeen thousand acres contained sufficient alkali in the first 6 feet to render certain precautions necessary to prevent injury of crops. Much of this land occurs south of Twelfth South street road where seepage and surplus waters have formed a chain of lakes. In the vicinity of these lakes the ground water is within a few feet of the surface, and unless some form of drainage is provided accumulation of alkali will undoubtedly increase. Where this amount of alkali (0.25 to 0.60 per cent) is found on higher, better drained soils no serious damage should result provided the surface be carefully leveled and all water be supplied in the form of heavy surface flooding at infrequent intervals.

Seventeen thousand acres was found to contain from 0.60 to 1 per cent of alkali, occurring in sandy soils with the water table usually about 4 feet from the surface. Generally the greater part of the alkali is concentrated in the lower depths of soil and attempts to cultivate this land are successful for a few years. With the rise of the ground water the alkali usually rises to the surface and many failures have resulted after cultivating such land, owing to the concentration of too much alkali in the upper layers of soil.

By providing even a limited amount of drainage and heavy surface irrigation many of these failures could have been prevented and the land maintained in fertile condition for a long period of years.

A large body of land, amounting to nearly 30,000 acres, contained from 1 to 3 per cent of alkali to a depth of 6 feet. The greater part of this class of alkali land is at present of no agricultural value except for the scanty pasturage it yields. Much of the alkali must be removed to make it available for crop production. In many locations, however, such land can be reclaimed and will then be found adapted to all classes of crops grown in the valley. More than 18,000 acres contained upward of 3 per cent of alkali, and on account of the heavy soils and low position it is to be doubted if such land can ever be profitably reclaimed. Conditions at the present time certainly do not warrant treating such soils when there are large areas of better land that can be made productive at a much less cost.

It was pointed out in the report by Gardner and Stewart that underdrainage was necessary not only to protect certain lands against injury from seepage waters and alkali, but also to reclaim lands already damaged; that the cost of underdrainage was slight in comparison to the value of alkali-free lands, and that money invested in drainage is in the nature of an insurance against loss of crops from seepage waters and alkali. Attention was also called to the fact that no serious engineering difficulties stand in the way of carrying out a comprehensive drainage system, that there is ample fall to the north and west toward the lake, and that the network of draws from 4 to 8 feet deep extending through much of the alkali land would furnish ready outlet for smaller drainage systems. It was further remarked that an area of nearly 100 square miles, which at present has but a mere nominal value, could be economically reclaimed, and that such work should appeal to the commercial spirit of the people and stimulate them to undertake this very desirable enterprise.

RECLAMATION OF THE SWAN TRACT.[a]

Several years after the publication of the Soil Survey report no important step had been undertaken toward any general scheme of reclaiming alkali lands. In 1902, therefore, the Bureau of Soils entered into cooperation with the Utah experiment station to demonstrate that alkali lands could be economically reclaimed. A tract of 40 acres was selected about 4 miles west of Salt Lake City, belonging to Mr. E. D. Swan. This tract is situated in sec. 5, T. 1 S., R. 1 N. The tract lies on the east of Williams Lake and has an elevation of about 8 feet above the bed of the lake. It was realized by all that if a tract of land of this character could be reclaimed there could be no possibility but that the reclamation of large bodies of land lying in this portion of the valley could be effected. The greater part of the tract was covered with a white crust of alkali and supported a scattering growth of greasewood (*Sarcobatus vermiculatus*). A railroad embankment crossed the tract from east to west, and city streets had been graded upon it many years before, when land speculation led many to believe that the city would rapidly extend its boundaries several miles to the westward of its present location.

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[a] From 1902 to 1904 W. H. Heileman was in charge of the reclamation of the Swan tract.

The surface soil consists of sandy and silty loam from 12 to 18 inches in depth. The underlying material varies from heavy loam to clay. In places a thin layer of sand occurs at a depth of 4 feet, while toward the lake, at an average depth of 26 inches, is found a white calcareous hardpan from 1 to 2 inches in thickness. Occasionally two layers of this hardpan are found, the first lying about 4 inches above the second. An alkali survey was made to determine the quantity of alkali contained in the soil to a depth of 4 feet. This showed that there was present in the soil to that depth from 2.5 to 5 per cent of alkali, consisting mainly of sodium chloride and sodium sulphate. Since 0.5 of 1 per cent of the alkali generally found in Salt Lake Valley represents about the upper limit of resistance of ordinary farm crops, it will be seen that the soil of the tract contained many times too much alkali for the growth of useful crops.

The following table contains analyses of representative samples of soil and subsoil taken from the Swan tract:

Chemical analysis of typical samples of soil from the Swan tract.

Constituent.	Sandy loam, 0–14 inches.	Loam, 14–30 inches.	Loam, 0–18 inches.	Clay loam, 18–42 inches.	Loam, 0–20 inches.	Clay loam, 20–40 inches.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soluble salt	1.64	1.34	2.43	2.60	2.46	2.28
Composition of soluble salt:						
Calcium (Ca)	1.22	1.04	.98	1.15	.81	1.05
Magnesium (Mg)	.48	.59	.49	.38	.48	.61
Sodium (Na)	30.77	29.51	32.79	33.24	31.61	33.26
Potassium (K)	4.39	4.76	3.62	3.07	3.64	2.80
Sulphuric acid (SO_4)	17.95	18.78	16.03	16.14	19.56	17.06
Chlorine (Cl)	34.33	29.36	39.27	41.02	36.66	39.40
Bicarbonic acid (HCO_3)	8.79	14.32	3.94	2.77	4.39	2.76
Carbonic acid (CO_3)	2.07	1.64	2.88	2.23	2.85	3.06

The ground water at this time (1902) stood at about 4 feet from the surface during the greater part of the irrigation season. In order to facilitate the removal of alkali salts by flooding, a drainage system was installed. The accompanying sketch map (fig. 2) shows the general plan of the drainage system and the size, depth, and interval between each lateral.

The average cost of the drainage system completed was $16.50 per acre. The system for the 40 acres includes 8 lateral drains and 1 main drain. Each of the laterals is 1,250 feet long and consists of 850 feet of 4-inch tile and 400 feet of 3-inch tile. The laterals were placed at intervals of 150 feet, except on the north side of the tract, where this distance was considerably increased to test the efficiency of drains at greater distances apart. The main drain across the west end of the tract consists of 520 feet of 6-inch tile, 300 feet of 8-inch tile, and 270 feet of 10-inch tile. The average depth of the drains over the entire tract was 4 feet. This was as deep as the system could be installed and secure a gravity outlet into Williams Lake.

In order that the water used in flooding the tract might be measured a Cipoletti weir with recording register was installed at the point where the supply canal entered the tract. A registering weir was also placed at the outlet of the drainage system to measure the water that passed through the soil. From the outset the drainage system worked perfectly and proved adequate to discharge all water drained through the soil.

On account of the fall, graded streets, and railroad embankment, leveling the tract so that systematic flooding might be carried on proved a laborious undertaking. An attempt was made to get the land in shape for flooding before the close of the irrigating season of 1902. A number of large checks were made inclosing a few acres each. Attempts to flood the tract, however, showed that more leveling was necessary to flood successfully the entire tract to a depth of several inches. This was done early in 1903, and flooding operations were continued during the greater part of the irrigation season. At the close of the season in 1903 a second alkali survey was made to determine the quantity of alkali removed by the flooding. This survey showed that large quantities of alkali had been removed, especially from the upper layers of soil. It was considered that the land was sufficiently sweetened to grow shallow-rooted crops. Accordingly in the spring of 1904 the tract was turned over to the Utah

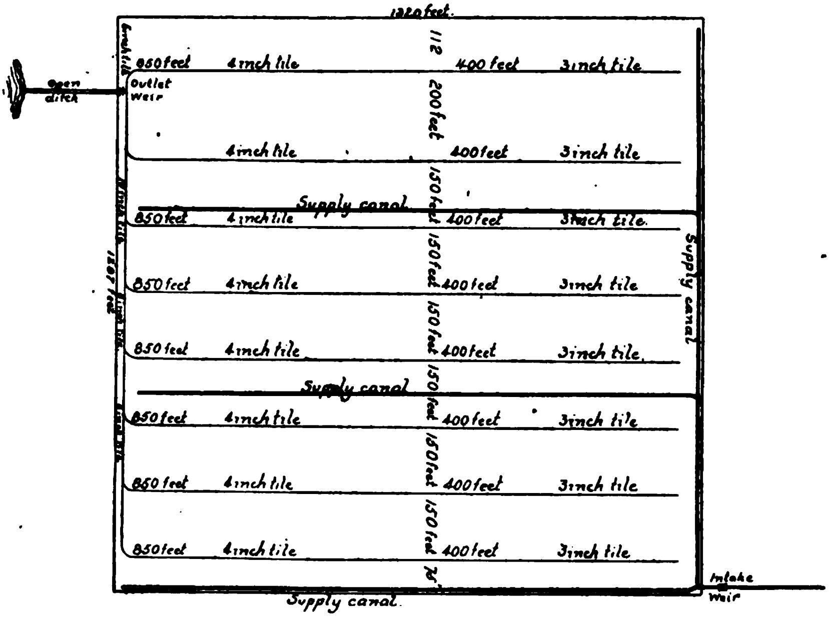

FIG. 2.—Plan of drainage system, Swan tract.

experiment station to conduct such crop tests. The entire tract was sowed during the latter part of May to wheat, oats, and barley. At this time the general tilth of the soil was not good on account of the flooding of the previous years. The soil somewhat resembles adobe, tends to bake or harden, and does not readily respond to cultivation. On account of the unfavorable physical condition of the soil the crop tests were not altogether satisfactory, but they plainly showed that the tract was already in condition for cultivation as far as the alkali content was concerned. Of the three crops the wheat made the best growth. Of the 40 acres planted about 15 per cent showed a thin stand where alkali still remained in the soil. The entire field headed short and showed the influences of late seeding. Early in August the greater part of the tract was plowed under to improve the physical condition of the soil. Flooding was then carried on for a period of several weeks, at the end of which time 10 acres were prepared and planted to winter wheat. By the spring of 1905 most of the wheat had made a good growth, but was thin and uneven in some places. The remaining 30 acres were planted to alfalfa and a variety of other crops, including potatoes, corn, berseem, beans, hemp, sugar beets, oats, barley, and spring wheat. There still remained some parts of the tract that had not been sufficiently leveled to secure the best results with irrigation, but in all parts of the tract, where water could be given the growing crops, results were very gratifying. No systematic flooding other than light irrigations was carried on during 1905. In 1906, 13 acres of the tract had a good stand of alfalfa, which had been planted the preceding season, and 4 acres were in winter wheat. The remainder of the tract was planted principally to alfalfa, using oats as a nurse crop. Other small portions of the tract were planted to crops requiring cultivation, such as corn, potatoes, and sugar beets. At the close of the irrigating season in 1906 the tract was practically turned over to the owner in a reclaimed condition. It is estimated that all excepting 1 or 2 acres of the tract contained so little alkali that no further damage from this source need be feared. A few small spots remained which still contained alkali in injurious amounts. These represent higher portions of the different checks which during the flooding operations had not been covered with water to a sufficient depth to leach out the alkali. The greater part of the tract is in alfalfa, and a very satisfactory stand has been secured. The fact that alfalfa can be successfully grown shows that the removal of the alkali has been very thorough, since it is well known that young alfalfa is one of the most sensitive crops to alkali.

At the beginning and close of each season an alkali survey has been made to determine the amount removed by flooding and the change in position of the alkali in the surface 4 feet of soil. The

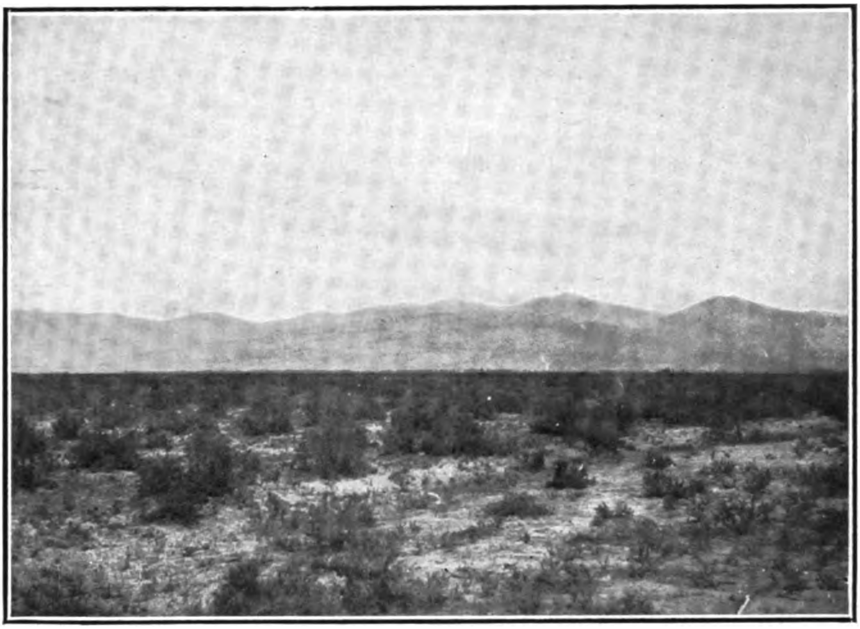

FIG. 1.—SWAN TRACT BEFORE RECLAMATION.

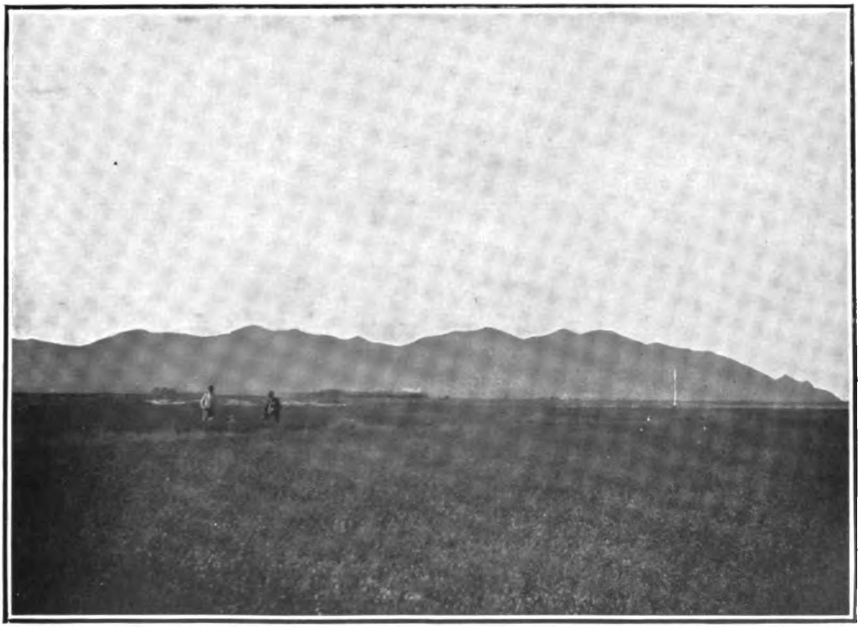

FIG. 2.—SWAN TRACT AFTER RECLAMATION, SHOWING HEAVY GROWTH OF ALFALFA.

following table shows the quantity of alkali in the tract as shown by the surveys taken at different times:

Quantity of alkali in different depths of soil on certain dates.

Soil section.	Alkali in 40 acres.							
	September, 1902.		May, 1903.		October, 1903.		October, 1904.	
	Tons.	*Per cent.*	*Tons.*	*Per cent.*	*Tons.*	*Per cent.*	*Tons.*	*Per cent.*
First foot	1,363	20	499	14	101	8	38	4
Second foot	1,540	23	650	19	183	15	128	13
Third foot	1,766	27	1,066	31	330	28	212	24
Fourth foot	1,982	30	1,265	63	607	49	500	57
Total	6,651	....	3,480	....	1,221	....	878	....

The alkali removed from the first foot between September, 1902, and October, 1904, was 97 per cent of the total quantity originally contained. From the second foot 91 per cent was removed, from the third foot 87 per cent, and from the fourth foot 75 per cent. These figures show that to a depth of 4 feet there has been 87 per cent of the original alkali removed from the entire tract.

Compared with its condition in September, 1902, the first foot of the tract contains only 3 per cent of the alkali originally carried, the second foot 9 per cent, the third foot 14 per cent, and the fourth foot 25 per cent. We find from this that the alkali has been removed most rapidly from the lower depths of the soil. It should be remembered that the alkali in the first 3 feet of soil had to pass through the fourth foot in its movement downward. The final elimination of alkali from the lower 2 feet of soil progresses more slowly than in the surface 2 feet. At the present time but little alkali remains in the first 2 feet of soil, and the elimination from the third and fourth should go on more rapidly.

The following table shows the volume of water added to the tract from September, 1902, until October, 1904. The table shows also the volume of drainage over the outlet weir, and the salts (alkali) removed from the tract in the drainage water. The results were obtained from continuous measurements and daily collections of water samples for the entire period.

Total quantity of water used in flooding the tract, quantity flowing off through drains, and quantity of salts removed in drainage water.

Month.	Volume of water added to tract.	Volume of drainage water from tract.	Salts in drainage water.
	Cubic feet.	*Cubic feet*	*Pounds.*
1902.			
September	284,400	158,700	152,200
October	940,000	265,000	195,100
November	[a] 171,300	251,000	353,800
December	[a] 166,500	139,700	187,800
1903.			
January	[a] 291,800	257,300	391,200
February	[a] 136,400	174,400	214,800
March	[a] 132,000	428,000	590,700

[a] Fell as rain or snow.

Total quantity of water used in flooding the tract, quantity flowing off through drains, and quantity of salts removed in drainage water—Continued.

Month.	Volume of water added to tract.	Volume of drainage water from tract.	Salts in drainage water.
1903.	*Cubic feet.*	*Cubic feet.*	*Pounds.*
April	[a] 112,000	26,900	26,500
May	[a] 576,900 760,900	521,500	567,100
June	[a] 106,000 676,500	274,500	345,200
July	[a] 36,580 1,691,970	480,490	556,459
August	2,122,160	814,890	1,221,742
September	2,352,920	1,195,976	1,654.115
October	351,290	663,420	840,981
November	563,376	113,137	126.364
December	40,656	50,376	43.953
1904.			
January	217,800	26,396	18.912
February	299,112	382,628	475,631
March	187,308	380,114	521.974
April	255,552	258,519	382.335
May	382,974	160,903	61,466
June	[a] 44,970 618,172	68,132	31.487
July	[a] 87,120 1,610,807	430,459	385.364
August	[a] 35,820 1,920,726	774,285	711.021
September	[a] 20,320 802,153	579,215	579.215
Total	17,896,486	8,775,940	10,635.419

[a] Fell as rain or snow.

From the initial installation to October 1, 1904, we have the following:

Total volume of water added	cubic feet	17,896,486
	acre-feet	410
Total tonnage of salts removed	tons	5,317

The initial tonnage of alkali in this tract in September, 1902, by a careful alkali survey, was 6,651 tons. From the above record it would seem that about all the alkali had been leached from the tract to a depth of 4 feet. It should be remembered that this tonnage was obtained from little more than half of the water actually added to the tract. One factor, however, remains undetermined, viz, the volume of water lost by surface evaporation.

Certain phenomena enter into the work which tend to show that the salt removed from the tract will finally exceed the actual tonnage originally present. We find the reclamation from alkali is not limited to the 40 acres in question, but that the effect of this drainage system is far-reaching. Unmistakable evidences appear which show that the land lying contiguous to the tract has been most definitely benefited by drains installed on the 40 acres. Lands lying above this tract, which in years past have never produced crops, have during the past season yielded almost normally. The drains near these lands have carried from them their underground water and the alkali which it contained.

The following table shows the quantity and composition of the constituents removed in the drainage water at various times during the progress of the reclamation. The proportion of the different constituents is remarkably uniform and should remain so until some one or more of the salts is completely removed as pointed out by Cameron.[a]

Chemical analysis of drainage water from Swan tract.

[In parts per 100,000.]

Constituent.	Seepage water from tile drain before irrigating October 9, 1902.	Drainage water June 18, 1903.	Drainage water April 4, 1904.	Drainage water May 10, 1905.	Drainage water June 26, 1906.
Calcium (Ca)	4.5	7.2	6.1	3.7	3.7
Magnesium (Mg)	9.6	25.7	16.2	7.0	8.9
Sodium (Na)	696.6	1,177.1	726.2	366.0	392.4
Potassium (K)	31.9	26.0	26.9	10.8	12.6
Sulphuric acid (SO_4)	387.0	888.6	353.1	214.3	228.8
Chlorine (Cl)	765.0	1,207.0	888.1	395.8	431.2
Bicarbonic acid (HCO_3)	132.9	93.7	80.0	66.6	69.5
Carbonic acid (CO_3)	7.1	5.5	4.0	5.9	6.0
Total solids	2,034.6	3,430.8	2,100.6	1,070.1	1,153.1

The following table shows the increased acreage of soil containing a low percentage of alkali. The columns headed "September" show the original acreage, while the columns headed "October" show present acreage. The results of later surveys are not included in these tables, since it was found that the alkali conditions over the entire tract were but little changed:

Acreage of land of different grades of alkali September, 1902, and October, 1904.

Per cent alkali present in soil (grade).	First foot.		Second foot.		Third foot.		Fourth foot.		Total in 4 feet.	
	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.
0.0-0.2	None.	38.8	None.	27.6	None.	17.0	None.	11.5	None.	23.7
0.2-0.4	3.0	None.	0.4	8.2	0.1	11.5	0.1	9.0	0.9	7.2
0.4-0.6	13.3	None.	2.3	3.2	.7	5.3	1.3	6.0	1.9	3.6
0.6-1	10.7	None.	8.0	None.	3.9	3.5	6.2	5.3	7.2	2.2
1-3	16.8	None.	19.7	None.	22.6	1.7	18.1	7.2	19.3	2.2
Over 3	5.0	None.	8.4	None.	11.5	None.	13.1	None.	9.5	None.

From the above brief description of the operations on the Swan tract it will be seen that excessive quantities of alkali can be removed from heavy soils by continuous flooding during a single irrigation season. The success of such an experiment can not but be far-reaching in its influence upon the alkali question in Salt Lake Valley.

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[a] The Composition of the Drainage Waters of Some Alkali Tracts. Jour. Am. Chem. Soc., Vol. XXVIII, No. 10, 1906. See also Bul. No. 33, Bureau of Soils.

It means that thousands of acres of land now lying idle can be made to produce profitable crops at a small outlay of time and money. While the present water supply is perhaps too limited to warrant the reclamation of all of the alkali areas, it is nevertheless adequate to reclaim a considerable proportion of the apparently worthless land.

METHODS USED IN RECLAIMING ALKALI LAND IN SALT LAKE VALLEY.

While there are abundant evidences that considerable land has been damaged by the accumulation of seepage water and rise of alkali, we must not lose sight of the fact that, since the earliest settlement in the valley, lands originally containing alkali have been reclaimed. Even at the present time the reclamation of alkali lands is progressing to a limited extent. That the question of alkali was considered serious by the settlers is brought out in some of the early writings. For instance, Charles Brough[a] states that "transformation of this sterile waste, glistening with beds of salts and soda and deadly alkali, seemed impossible." From this quotation it must not be inferred that any large bodies of land containing excessive quantities of alkali have ever been reclaimed. There are reasons to believe that, taking the valley as a whole, the quantity of alkali is decreasing, especially on the higher sloping lands which are better drained. Mention is made by some of the old settlers of the fact that in former times the year's supply of salt could be gathered from some one of the numerous small lake beds which occur in large numbers in the level valley between the Jordan River and the shores of Great Salt Lake. At the present time, while these ponds dry up during the summer season and crusts of alkali are formed on the surface, in no places can large quantities of salt be gathered by merely shoveling up the surface deposit. From this it may be inferred that as new tracts of land are being put under irrigation the alkali is gradually being driven into underground drainage channels and slowly working its way to Great Salt Lake.

The methods which are at present used in reclaiming alkali lands may be described under the heads of cultivation, washing, and flooding combined with drainage.

CULTIVATION.

Utilizing small tracts of land by thorough cultivation and planting crops is practiced not only in the Salt Lake Valley, but in many districts in the Pacific Coast States, especially by Chinese farmers and gardeners. A tract of land is selected usually of not more than a few acres, which on account of its alkali content is not considered valuable, and hence offers a cheap home site to the man of limited capital. By thorough cultivation the land is put in the best possible shape for crops, which are planted and make a successful growth. By spading or deeply plowing the soil the alkali accumulated at or near the surface is evenly distributed through the soil to the depth to which it is stirred. The soil is also made loose and porous, so that rains or applications of irrigation water tend to drive the alkali salts to a lower depth. The upper soil is then sufficiently reclaimed to permit the growth of crops which shade the surface, while repeated cultivation checks further rise of alkali. Each succeeding irrigation tends to drive the alkali deeper into the subsoil, until the greater part of it is carried away into the country drainage. Thus these small tracts of alkali land are made productive, frequently with no thought on the part of the owner that he is actually reclaiming the land. Could this method be adopted on a large scale or the land subdivided into a large number of small holdings and thoroughly cultivated, there is little doubt that large tracts of land in Salt Lake Valley could be made productive. Frequently in following out this method of reclaiming alkali soils large quantities of stable manure are worked into the soil, which tends to make the soil more open and allows the more ready percolation of rainfall and irrigation water. The addition of manure also serves as a stimulant to young crops, thereby enabling them to withstand whatever alkali may still remain in the upper layers of soil.

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[a] Irrigation in Utah.

WASHING.

This is also a favorite method when an attempt is made to cultivate somewhat larger tracts of land than are mentioned in the above paragraph. Fields of 10 and 20 acres are selected which in their present condition are considered too strongly charged with alkali to grow crops. Sufficient leveling is done to get the land in shape for irrigation. When the land has been leveled so that all parts of the tract may be covered with water to a considerable depth, heavy irrigations are used during longer or shorter periods as required. In this way large quantities of alkali may be washed off the surface or driven to some depth in the soil. With the ground water at a depth of 4 or 5 feet from the surface the amount of alkali driven into a lower depth of soil with that removed from the surface by washing may sufficiently sweeten the land to permit growth of crops. Irrigation after the crop has become partially established is relied upon to further reduce the amount of alkali in the upper layers of soil. It is undoubtedly by this method that the early settlers reclaimed extensive areas on the east side of the valley. The slope in this portion of the valley is usually pronounced, and other conditions are favorable for removing the alkali originally contained in the soils. During the progress of the demonstration work on the Swan tract a small piece of land near by was reclaimed in this manner. Flooding was carried on at various times during the year, to be followed in the succeeding spring by a crop test. While this work was unsuccessful for the first two or three years and the crop returns did not pay for the cost of seeding, eventually this method was successful and the land now supports a fine stand of alfalfa. As late as the latter part of the summer of 1904 the surface was heavily incrusted with alkali salts. In 1905, the year in which the crop of alfalfa was established, a test of this soil was made to a depth of 3 feet in places where the stand of alfalfa was thin. It was believed that the alfalfa in these places was actually tolerating a high percentage of alkali. These tests showed that none of the soil to a depth of 3 feet contained sufficient alkali to injure alfalfa even in its younger stages. The ground water at this time stood within 3 feet of the surface.

Before attempting the reclamation of any considerable tract of land by this method it will be found advisable to determine accurately the depth of the ground water. As a general rule, if the ground water occurs within 3 feet or less, considerable difficulty will be found in leaching out large quantities of alkali by flushing or irrigation. If, however, the ground water is at a depth of 4 feet or more and the soil of open, sandy texture, washing, especially during the late summer season, will so reduce the quantity of alkali that crops may be grown the succeeding spring.

FLOODING COMBINED WITH DRAINAGE.

While no extensive attempts at reclaiming alkali lands have been undertaken by drainage combined with flooding, there are a number of interesting examples which deserve attention. In the vicinity of Granger, about 10 miles southwest of Salt Lake City, a number of farmers have successfully reclaimed land damaged by high ground water and accumulations of alkali. Some of the farmers who have undertaken this work are enthusiastic over the results, and each year continually increase the extent of their drainage systems. Drains consisting of ordinary drain tiles have been used in some cases, but equally good results have been obtained with drains made of boards. In some cases land originally covered each year by a heavy crust of alkali, with the water table near the surface, has been reclaimed in one year's time and now supports a heavy growth of alfalfa. While it has been realized by these farmers that the cost of installing the drainage system was considerable, they have been amply repaid by the increased growth of crops for the time and money expended.

Drainage systems with open ditches have also proved successful in a few instances. A greater part of the soils in the level portions of the valley stand well in bank and only require cleaning once or twice each year, so that this form of drainage system can be utilized by the farmer of limited means who can not afford to purchase tile.

RECOMMENDATIONS FOR RECLAIMING ALKALI LANDS.

Before attempting the reclamation of any considerable tract of alkali land in Salt Lake Valley it is desirable for the farmer to consider the demonstration work on the Swan tract and other methods which have been used by the farmers of the valley. This work plainly shows that one of the most essential features is that the land must be placed in condition so that it can be entirely covered by irrigation water. Even with efficient drainage systems, if high spots remain in the fields which can only be covered to a very slight depth with water, these places will tend to hold and accumulate the alkali from the surrounding land. This does not necessarily imply that the land must be made perfectly level, but it must be so graded that an even flow of water across it may be had to secure uniform leaching. Where the land has only a slight fall it will be found desirable to divide the land into checks so that the water may be held on the land. It has been the experience of the Bureau of Soils on the Swan tract and elsewhere that the best results have been secured with a considerable depth of water. Light irrigations carry the alkali to a depth of a few inches, and when the soil dries off it readily returns to the surface, as previously explained. Flooding to a depth of 10 or 12 inches drives the alkali deeply into the soil, while succeeding floodings carry it still farther into the soil, thereby diminishing the chances for a second accumulation at the surface when conditions become favorable. It will be found desirable to plow the land to a good depth before each flooding in order that the water may more readily percolate the soil. On sandy soils that are open and porous plowing may not be necessary to effect a rapid downward movement of the water. Plowing the land at the close of the irrigating season will check evaporation and allow the soil to catch and hold any rain or snow that falls. Plowing in the fall is to be recommended for alkali land, no matter what method of reclamation is used to remove the salts.

The question of deciding whether or not drainage is necessary to reclaim a certain piece of land will depend on the quantity of alkali present, the character of the soil, and the depth to standing water. With porous sandy soils, only moderate quantities of alkali, and the ground water at a depth of 4 feet or more, heavy flooding for a few months will so reduce the alkali content that useful crops may be grown. To keep the land free from alkali heavy surface irrigation should be resorted to. This will drive down whatever salts are carried upward by the capillary rise of the soil moisture. At any time should the ground water rise within a few feet of the surface gradual accumulation of alkali may be expected. Should the practice of occasional heavy surface irrigations be discontinued alkali will undoubtedly increase in the upper layers of soil. Many examples have been recorded where land reclaimed in this way has again been ruined by a second accumulation of alkali. Such examples have probably prejudiced many farmers against freeing land from alkali by this means.

Where large quantities of alkali are contained in heavy clayey soils this method becomes of more doubtful application. The quantity of water necessary to wash the alkali to the point where it will no longer harm crops may be sufficient to raise the ground water, thereby defeating the object of the experiment. Again, the length of time involved in reclaiming such soils must be considered. While it may be possible eventually to reclaim heavy soils containing much alkali, the time necessary to do this will probably be so great that it will be far cheaper to drain the land to hasten the reclamation and put the land in crops. Frequently crop returns from productive land amount to from $20 to $50, and even more, an acre. From this it will be seen that it would be well worth from $15 to $20 an acre, the cost of a drainage system, if by this expense the farmer can get his land into paying crops one year sooner than he could by flooding alone. The question of the permanent reclamation also enters, for unless the land be naturally well drained and carefully managed alkali may accumulate in even greater quantities than were originally present.

DRAINAGE.

Aside from the ease and rapidity with which land may be reclaimed after a drainage system has been installed, there are several other reasons why drainage is to be recommended. In countries of abundant rainfall the good effects from drainage are appreciated and much land is drained where the removal of an excess of water is not absolutely necessary. The observant farmer has learned that drained land can be cultivated earlier in the spring and is warmer; that excess of rainfall is rapidly drained away, while sufficient moisture is retained in the soil to maintain a vigorous growth. In an arid region drainage will for these reasons add to the value of the soil aside from the question of removing alkali and seepage waters. Drainage may be accomplished by pumping plants that depend upon shallow ground water for their supply or by the use of gravity drains that will conduct the water to some natural outlet or to a sump dug for the purpose, from which it is raised. Either method is capable of lowering the ground water. If the drainage water does not contain soluble salts in large quantities, pumping may be used to furnish water for irrigation purposes. If, however, the drainage water contains too much salt to be applied to crops, it will be better to depend on a gravity system of drains. No great difficulty will be experienced in finding a gravity outlet in the Salt Lake Valley, as the land has ample fall and there is a network of narrow depressions that finally discharge into Great Salt Lake.

A drainage system to reclaim alkali land differs somewhat from the drainage systems commonly used in regions of abundant rainfall. To secure the best results the drains are placed at a greater depth and at a correspondingly increased distance apart. On the Swan tract, in heavy soils, drains placed 200 feet apart were apparently as successful as those placed 150 feet apart. On the light sandy loams where the alkali occurs in moderate quantity the drains may be placed at intervals as great as 250 and 300 feet. On the heavy clay soils with a large amount of alkali intervals of 150 feet between drains will be more satisfactory. Drains should be placed at least 3 feet deep, and depths of 4, and even 5, feet will repay the extra cost in laying them at this depth. The depth at which the drains are installed will be found to be about the depth to which the alkali can be leached from the soil. While 3 feet of alkali-free soil may be sufficient for most crops, underlying layers of soil containing alkali will be a possible source of danger, depending on the capillary power of the soil to lift the alkali to the surface. Each additional foot of soil that can be freed from alkali thereby decreases the chances of a second accumulation of alkali in the upper layers of soil. Four or 5 feet has been found to be a good depth to install drains, as most soils will accumulate little alkali when once it has been leached to this depth.

Open ditches are equally as effective as closed drains and have been extensively used in Egypt and other alkali districts in northern Africa.[a] Open ditches need frequent cleaning, occupy valuable space, must be bridged to transport farm machinery across fields, and frequently prove troublesome when flooding the land. For these reasons open ditches for small-field drains have not been extensively used in this country, although they are generally used for large-main drains that receive the surplus waters of many small drainage systems.

For closed drains tiles of burned clay or boxes of boards or planks may be used. Flat stones are frequently used for closed drains, as well as bundles of brush tied together and placed end to end. Since drain tiles have proved the most economical form of drainage implement, their use is generally to be recommended. For information in regard to laying tile and planning drainage systems the reader is referred to Farmers' Bulletin No. 187, entitled "Drainage of Farm Lands," and "Engineering for Land Drainage," by C. G. Elliott, of the Office of Experiment Stations. Tiles smaller than 4 inches have not given satisfaction in draining alkali lands on account of the difficulty in keeping them free from silt. The tiles should be crowded closely together and silt catchment basins constructed in long lines of tile. It will generally be found advisable to construct these of sufficient size, so that the deposits of silt may be easily removed. Boxes made of boards or planks 4 or 5 feet long and 2 feet wide and at least 1 foot deeper than the tile have been found satisfactory. In Salt Lake Valley no unusual difficulty will be found in keeping the tiles free from silt, for the subsoils are usually heavy. After the tiles are laid care should be taken to settle the earth firmly over them. This may be done by filling to a depth of several inches and allowing a small stream of water to enter the trenches before filling in the entire trench. When once the earth is firmly settled over the lines of tile and it is found that silt does not enter the tiles, the land may be flooded over the lines of tile. If, however, much silt enters the tiles banks of earth or levees should be thrown up to protect the lines of tile. On the Swan tract little, if any, silt enters the tiles, and precautions necessary to keep the tiles open elsewhere were not considered.

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[a] Reclamation of Alkali Lands in Egypt, by Thomas H. Means, Bul. 21, Bureau of Soils. 1903.

After the drainage system is installed the land should be divided into checks so that flooding can be carried on. Flooding is necessary to hasten the final reclamation. Drainage may effectually check any further accumulation of alkali, but the alkali contained in the soil will not be removed until sufficient water is added to leach it downward through the soil. Heavy rains that penetrate the soil to the depth of the drains are valuable adjuncts to flooding, but in arid countries the ordinary rainfall can rarely be depended upon to remove the alkali entirely. A good depth of water even at infrequent intervals is more effective than frequent applications of a few inches of water, as explained elsewhere. More time will be necessary to leach alkali from stubborn clay soils than from sandy soils, through which the water readily percolates. On the Swan tract, with heavy soils and excessive alkali content, flooding for one season so reduced the alkali that shallow-rooted crops could be grown the following season. From this it would appear that, with an adequate drainage system and the land nicely leveled for flooding, the land should be occupied with profitable crops the succeeding year. In the case of heavy soils the growth of shallow-rooted annual crops is advised before planting a permanent crop, such as alfalfa. During the flooding operations the tilth of the soil may be destroyed and the cultivation and plowing under of stubble will help overcome the bad effects of water-logging the soil. Oats will be found a good crop to plant on newly reclaimed alkali lands. Oats withstand considerable alkali, make a rapid growth, and find a ready sale at good prices in Salt Lake City. This crop has also been found a good nurse crop for alfalfa when the latter is seeded. On the Swan tract alfalfa sown with oats as a nurse crop made fully as good growth as alfalfa without a nurse crop, and there was gained the crop of oats while the alfalfa was getting established the first year.

It was observed that the flooding necessary to reclaim the land had not in any way impaired the productiveness of the soil, as the stand of alfalfa was pronounced as satisfactory as that secured on alkali-free soils in different parts of the State.

The cost of reclaiming alkali land in Salt Lake Valley will depend on the methods employed, the character of soil, and the quantity of alkali. With light sandy soils, little alkali, and deep ground water, cultivation and surface irrigation will be all that is necessary and the cost will be slight. The land must be prepared for surface irrigation, which will cost from $2 to upward of $30 an acre, depending on the character of the surface. There are large tracts of land in the valley where the amount of leveling will be small and the cost should not exceed $5 an acre. The cost of the cultivation and irrigation will also be low, so that $10 or $15 an acre will be sufficient to reclaim comparatively level sandy soils.

When a drainage system is necessary, as well as flooding for several months, the cost will be much greater. The drainage system on the Swan tract cost about $16.50 an acre and may be taken as an average cost of similar work in the valley. The cost of flooding for one year will vary from $5 to $10 an acre. By many it will be urged that the cost of leveling the land should not be included in the cost of reclaiming land, since all recognize that the land must be leveled before it can be successfully irrigated regardless of the presence of alkali. Deducting, then, the item of leveling, the cost of reclaiming alkali lands in Salt Lake Valley, even when drainage must be resorted to, will be from $20 to $35 an acre, surely a small outlay when the increased earning capacity of the soil is considered.

SUMMARY.

In previous pages it has been shown that extensive tracts of land in Salt Lake Valley west of the Jordan River are not productive on account of alkali. On account of the nearness to excellent markets it is highly desirable that the farmer should know how to remove the alkali. Reclaiming alkali land to a limited extent has been practiced since the first settlement in the valley in 1847, but no extensive work has been undertaken by private enterprise. An experiment on 40 acres of worthless alkali land 4 miles west of Salt Lake City, conducted by the Bureau of Soils and the Utah experiment station, showed that such work is practicable, since the reclaimed land now supports a good stand of alfalfa. These results were accomplished by heavily flooding the land after a drainage system had been installed. It was found that surface flooding for one year leached away large quantities of alkali from heavy soils; in fact the quantity of alkali was so reduced that shallow-rooted crops could be grown the following year. The cost of reclaiming this tract of land is not large in comparison to the enhanced value of the land. This experiment in reclaiming worthless alkali lands should prove an incentive to those seeking homes at moderate cost, or to men of larger capital interested in employing their means in safe investments. Much of the now idle land in Salt Lake Valley can be made to yield handsome returns by a limited outlay of time and money. Even those lands that, on account of the necessity of providing drainage systems, will require more effort to get rid of the alkali will be often found far cheaper than new lands now being developed in many parts of the West where market facilities and social and educational advantages are lacking and no definite information can be secured as to what crops may be successfully grown.

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 44.

MILTON WHITNEY, Chief.

RECLAMATION OF ALKALI SOILS AT BILLINGS, MONTANA.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., May 1, 1907.

Sir: I have the honor to transmit herewith a paper entitled Reclamation of Alkali Soils at Billings, Mont., by Clarence W. Dorsey, of this Bureau. This paper details the general conditions of this part of the Yellowstone Valley as regards alkali and seepage water, and gives an account of the reclamation demonstration carried on near Billings on the O'Donnell tract. The results of the work at Billings have been very gratifying and, I believe, have resulted in awakening general interest in the question of reclaiming these alkali lands, both by the farmers privately and in cooperation with the State.

I recommend the publication of this report as Bulletin No. 44 of the Bureau of Soils.

Very respectfully,
Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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RECLAMATION OF ALKALI SOILS AT BILLINGS, MONTANA.

INTRODUCTION.

Billings is situated in southeastern Montana, in a long, narrow valley characteristic of the lower Yellowstone River in the eastern part of the State. The valley is bounded on the north by sharp sandstone bluffs, rising from 200 to 500 feet above the valley floor. On the south in places bold bluffs of blue shale sharply define the valley or it merges into a mass of rounded hills that increase in height at greater distances from the river. The river occupies the lowest trough in the valley while successively higher terraces of low elevation give character to the surface relief of the valley. The terraces are marked by steep faces on the river side and extend as wide, level plateaus in places attaining a maximum width of 4 miles. They bear a definite relation to the course of the river and mark the various stages in the formation of the valley.

Billings has an elevation of 3,119 feet above sea level. The climate is characterized by extremes of heat and cold and an annual rainfall of about 15 inches, the greater part of which occurs during the spring and early summer months. The climate may be classed as typical of the great semiarid plains lying east of the Rocky Mountains.

At the time of the settlement of the valley only a very small proportion of the land showed any sign of alkali. The areas where alkali was plainly in evidence occurred in the eastern part of the valley and in occasional areas below the higher bench line. Near the present site of Billings and east to the river only alkali-resistant vegetation grew abundantly and there was sufficient alkali in places to form a crust. There were also other areas scattered throughout the valley that contained more or less alkali. With the construction of the Minnesota and Montana Improvement ditch in 1882 irrigation began, but the rapid settlement and development of the valley did not take place until 1890. About four years later, when large areas were under irrigation, damage from seepage water was first noticed. Some of the lower lands became too wet for cultivation and were given over to the growth of rushes and other water-loving plants. Other areas of water-logged soils appeared, increased in size, and were abandoned when cultivation was no longer possible. Not only were the lands damaged by the rise of the ground water, but alkali also appeared in increasing quantities and proved more serious than the injury from excess of water.

This damage continued for many years and the situation appeared serious indeed. Many farmers abandoned their farms and moved to other parts of the valley where cheap lands could be obtained. In the last few years, however, the situation has become more encouraging and conditions at the present time are such that the farmers of the valley need no longer fear alkali. It has been found that the alkali is confined to certain well-defined areas and is not extending beyond the boundaries of these areas, which do not aggregate more than 10 per cent of the area of the entire valley. An active interest in the subject of drainage has resulted in the formation of drainage districts, and already several large drainage systems have been completed, with others contemplated in the near future. Besides this important work the reclamation of a tract of alkali land by the Bureau of Soils has shown that it is comparatively easy to restore the damaged lands to their former productiveness by methods well within the reach of the progressive farmers of the valley.

SOIL AND ALKALI CONDITIONS IN THE VALLEY.

The alkali situation was first called to the attention of the Bureau of Soils in 1897. In that year Professor Whitney spent a few days in making a rapid reconnoissance of the valley. He found that there was much uncertainty on the part of the farmers as to just what the conditions in the soil were. It was then decided that a more thorough study of the valley should be made, to determine, if possible, the conditions in the soil, the possible results if present methods were continued, how to prevent the spread of alkali, and what should be done to reclaim the already abandoned lands. Such an investigation was made in the summer of 1898 by Mr. Thomas H. Means, and the results were published as Bulletin No. 14 of the Bureau of Soils.

RESULTS OF ALKALI STUDIES MADE DURING 1898.

Concerning the source of the alkali it was found that the farmers had advanced many theories and there was widespread belief that the alkali flats could probably be reclaimed by flooding the surface during a dry season and washing the crust off. Determinations of the amount and location of the alkali in the soil plainly showed that the crust contained only a small proportion of the alkali and that such a method would be inefficient. In every case of injury to crops that was examined it was shown that the first trouble was an accumulation of seepage water near the surface, and, while the water did not contain excessive quantities of alkali at first, continued evaporation resulted in concentrating sufficient alkali at the surface to injure crops.

An examination of the structure of the valley showed that it had been carved out of sandstones and underlying shales. The sandstones that rise abruptly above the valley on the north are porous and carry small quantities of magnesium and sodium sulphates, which frequently appear as a white incrustation on the bare rock surface. The soft blue shales forming the boundary of the valley on the south are penetrated by numerous fine cracks and joints filled with fibrous gypsum, while larger cavities carry gypsum and calcium carbonate. Throughout the mass of the shales are found large quantities of sodium and magnesium sulphates, which form a white incrustation on the surface.

The soils of the valley were found to have been formed from the weathering of these shales and sandstones, modified and deposited by stream action. So it would appear that the rocks are directly responsible for the soluble salts contained in the soils, these salts consisting principally of sodium and magnesium sulphate. The sandy soils occurring in the valley have been derived largely from the sandstones, and hence contain originally less salts than the heavy soils that have been derived from shales.

A detailed study was made of sec. 2, T. 1 S., R. 25 E., and maps were prepared showing the alkali and underground water conditions. These maps clearly showed the relation of seepage waters to the accumulation of alkali and how essential such a study is to the proper understanding of the question of providing remedies to check further damage. A study was also made of the quantity of salts being removed by a drainage ditch surrounding the town of Billings, which had been constructed to intercept the seepage waters from higher irrigated lands. From this it was found that the flow of water in the ditch was about 40 second-feet and that about 16½ tons of salt per hour was being removed; that is, it was rapidly carrying away the alkali seepage waters, thereby checking the concentration of alkali in adjoining lands.

The investigation further showed that before irrigation the salts were present, but so evenly distributed throughout the soils that they were not injurious to crops. The injury was found to be due to overirrigation, to the translocation and local accumulation of salts by seepage waters, to the imperfect drainage facilities in the clay soils, and the inability of the soils to remove the excess of salts and seepage waters. It was pointed out that the only way to prevent the final abandonment of the land containing alkali was to provide underdrainage systems to carry off the excess of water and the accumulated salts, but that the conditions in the valley were very simple, and that the rise of salts might be easily prevented.

RESULTS OF THE SOIL SURVEY OF THE BILLINGS AREA IN 1902.

During the summer of 1902 a more thorough study of the soil and alkali conditions of the Yellowstone Valley was made by Charles A. Jensen and N. P. Neill. The area surveyed extends from 1 mile west of Park City to a short distance east of Billings, in all nearly 25 miles. The valley has a maximum width of 7 miles about 8 miles west of Billings, but narrows in each direction from this point. The area surveyed comprises about 107 square miles (68,416 acres). The most extensive type of soil was found to be the Billings clay, with an area of slightly more than 17,000 acres. It is locally known as "gumbo," and is a dark-gray or black tenacious clay, often many feet deep and in such places practically impervious to water. When once the clay subsoil becomes filled with water drainage is exceedingly difficult. It has largely been derived from the Fort Benton shales that underlie the sandstones. Although it is difficult to cultivate, it produces good crops of timothy, blue stem, redtop, June grass, and other grasses, where the alkali content is low.

The Billings loam covers an area of more than 14,000 acres, and consists of about 12 inches of heavy loam overlying a light clay loam. It is also a dark-colored soil, but is easy to cultivate, and where there is little alkali is adapted to grain, vegetables, alfalfa, and other crops. Another extensive type of soil was found to be the Billings sandy loam, occupying an area of 13,568 acres. The top soil is a sandy loam to 12 inches overlying a light-yellow sandy loam which extends to a depth of several feet, and rests upon gravel, sand, or fragments of sandstone. This soil, unlike those just described, does not generally occupy the wide level terraces, but forms the gentle slopes of the foothills of the sandstone bluffs. It has been derived largely from the breaking down of the sandstones, has excellent underdrainage, and accumulations of alkali are rarely present. It is a rich, warm soil, well suited to any of the crops grown in the valley. Other types of soil are the Billings gravelly loam, a sandy loam mixed with waterworn gravel, and the Laurel sandy loam occurring along the river, where it frequently is made swampy by the seepage from higher lands.

The irrigation water supply for the valley is taken from the Yellowstone River and is ample for all purposes. The water is conveyed to different parts of the valley by gravity canals, some of which are many miles in length. The flow of water in the Yellowstone during the early summer months is large, at times the mean flow for May and June being upward of 10,000 second-feet. Since the water of the Yellowstone is principally derived from melting snow, the quality is excellent for irrigation. An analysis showed only 130 parts of soluble matter per 1,000,000. Some irrigation is done with seepage water, usually with bad results on those soils already containing some alkali, since such water generally carries considerable salt in solution.

An examination of many samples of well, drainage, and spring waters showed all to contain soluble salts in quantity; well waters are especially bad, many containing from 1,700 to 9,000 parts per 1,000,000. Wells with the highest salt content are located in the level areas of Billings clay. Wells more free from salt are located on gravelly terraces, where the underdrainage is quite good. Springs along the river bank as a general rule are too salty for domestic purposes. The large quantity of salts found in the subsoil and drainage waters forcibly indicates the presence of accumulations of alkali in the subsoil and insufficient underground drainage. The salts found in these underground waters consist mainly of sodium, magnesium, and calcium sulphate.

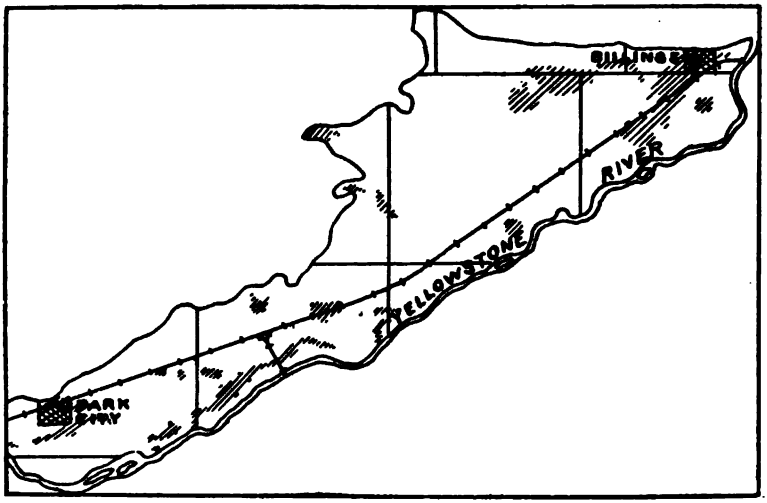

FIG. 1.—Map showing general distribution of alkali lands. Hatching shows affected areas.

During the soil survey of 1902 a map was prepared showing the various grades of alkali land in the valley. In general it was found that the heavy clay and loam soils carried the most alkali. Alkali was not always found, however, in all of the clay areas, as some have a light subsoil and the underdrainage is good. The accompanying sketch map, prepared from the alkali map contained in the 1902 report, shows the extent and distribution of soils containing more than 0.60 per cent of alkali to a depth of 6 feet. It was found that of the area surveyed (68,416 acres) 42,944 acres contained less than 0.20 per cent (2,000 parts per 1,000,000) of alkali; that is, the quantity of alkali to a depth of 6 feet was so small that the effects on crops were negligible. Eighteen thousand six hundred and twenty-four acres contained from 0.20 to 0.60 per cent of alkali (2,000 to 6,000 parts per 1,000,000), and while the damage due to alkali was not great, in case all of the alkali became concentrated in the upper layers of soil injury would undoubtedly result. An area of 5,568 acres contained from 0.60 to 1.0 per cent of alkali, which is a little too much for the crops generally grown in the valley. Only 1,344 acres contained more than 1 per cent of alkali, and in their condition at that time (1902) were of little agricultural value. From these figures, representing the various grades of alkali, as well as from an inspection of the small sketch map, it will be seen that only about one-tenth of the area contains sufficient alkali to be a serious menace to crops.

In general it was found that the vertical distribution of the alkali is governed by the texture of the soil and subsoil and by the position of the soil and subsoil. In uncultivated areas of clay soil where alkali occurs its distribution below the first foot is quite uniform, the maximum quantity being found generally at a depth of 5 feet. Where the soils are heavy clay but have lighter subsoils the maximum alkali content is in one of the upper 3 feet of soil, but less alkali is found in the lower depths, the quantity depending largely upon the height of the ground water. In the deep clay soils where irrigation has been judiciously carried on the greatest quantity of alkali is found at a depth of from 3 to 6 feet. On some of the wide, level terraces and lower alkali lands along the river there is generally a surface accumulation of alkali with the maximum salt content in the first or second foot. In these localities the ground water is quite near the surface and within easy reach of the upward capillary power of the soil.

Above the canal in the sandy soils that have not as yet been irrigated little or no alkali was found in the soil to a depth of 6 feet, but moderate quantities were usually encountered at 7 and 8 feet, generally increasing with the depth. The alkali in the alluvial sandy loams found along the Yellowstone has resulted from evaporation of seepage water from higher lands. As before noted, the alkali in the higher bench and terrace soils has been derived directly from the breaking down of the sandstone and shale rocks, especially the latter, which are rich in soluble salts.

The general distribution of the larger alkali areas bears a direct relationship to the topography of the valley. As has been stated, the valley floor is marked by wide terraces, with a sharp bluff of from 15 to 30 feet emphasizing the line of demarcation between the different terraces. The outer or southern edge of these terraces is almost invariably higher than the central portion, and in places is even higher than the northern part. As a result of these topographic conditions, the depressions first became swampy as overirrigation was practiced on the higher soils. The irrigation water, as it slowly soaked through the soil, dissolved the salts and carried them to the troughlike depressions. Evaporation of much of this water concentrated the salts, and these swampy areas were finally abandoned as alkali flats. The poor underdrainage of the clay soils has materially hastened this process of converting water-logged lands into alkali swamps.

The following table contains analyses of samples of alkali crusts and soils. The samples are typical of the alkali found in the soils in the Yellowstone Valley. It will be noticed that sodium sulphate predominates, with much smaller quantities of calcium and magnesium sulphate. The chlorides and bicarbonates are present only in small amounts, with traces of alkaline carbonates.

Chemical analyses of salts of typical alkali crusts and soils of the Billings area.

Constituent.	6600. Near NW. corner sec. 2, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6601. Center sec. 10, T. 1 S., R. 26 E., soil 0 to 10 inches.	6602. Center sec. 10, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6603. S. center sec. 9, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6604. Center sec. 8, T. 1 S., R. 26 E., crust 0 to 1 inch.	6605. W. center sec. 34, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	0.79	2.99	0.16	3.63	4.14	1.85
Magnesium (Mg)	1.79	.85	.24	2.01	2.57	2.95
Sodium (Na)	28.16	20.56	31.73	23.51	22.06	25.03
Potassium (K)	.72	9.63	.88	2.78	2.79	1.08
Sulphuric acid (SO_4)	67.73	45.85	59.93	62.98	61.06	66.49
Chlorine (Cl)	.33	Trace.	1.48	3.24	4.70	1.54
Bicarbonic acid (HCO_3)	.48	16.06	2.83	1.85	2.68	1.06
Carbonic acid (CO_3)	Trace.	4.06	2.75	....	....	....
Conventional combinations:						
Calcium sulphate ($CaSO_4$)	2.71	10.07	.55	12.29	14.00	6.08
Magnesium sulphate ($MgSO_4$)	8.90	4.06	1.22	9.91	12.76	14.58
Sodium sulphate (Na_2SO_4)	85.57	35.12	85.06	66.66	55.68	72.93
Potassium sulphate (K_2SO_4)	1.60	21.41	1.96	6.18	6.15	2.41
Sodium bicarbonate ($NaHCO_3$)	.67	22.06	3.90	2.55	3.69	1.46
Sodium carbonate (Na_2CO_3)	Trace.	7.28	4.87	....	....	....
Sodium chloride (NaCl)	.55	Trace.	2.44	5.41	7.72	2.54
Per cent soluble	44.68	.934	17.00	2.59	1.79	9.04

It is the exception to find in an arid country alkali consisting mainly of sodium sulphate; in most cases sodium chloride is the predominant constituent. As compared with the type of alkali found in other districts, the Billings type is generally supposed to be the least injurious to field crops. Some determinations as to its effects on crops were made in the different years during which the Bureau studied the alkali conditions in the valley, as well as in 1906, when the reclamation work was in progress. From the following statements it will be noticed that in general the crops are able to withstand more alkali than in areas where sodium chloride or the more toxic sodium carbonate prevails.

Although 1906 was the first year in which sugar beets were grown, it seems that they are the most resistant crop to alkali that is grown in the valley. Fields were found where the beets were growing in from 0.60 to 1 per cent of alkali, while the surface foot contained nearly 1 per cent. Alfalfa, after it has become well established, comes next in resistance, as it has been found in good condition in soil averaging a little over 0.60 per cent. In one place, where the water table was about 4 feet below the surface, alfalfa was in poor condition, with an average of 0.50 per cent of salt present. Oats have been found growing in soil containing 0.85 per cent and 0.91 per cent of alkali, as averages for 6 feet. The plants in both cases were small and weakly, and were only surviving. These limits are, of course, too high to be taken as a guide for the resistance of this crop, but shows how much salt can be tolerated by some individual plants. Good oats were found growing in soil with 0.58 per cent as an average for 6 feet and with no surface accumulation. Only one field of wheat was noticed where there were alkali spots. At the edge of these spots, where the wheat was dying, the soil averaged only 0.20 to 0.40 per cent to a depth of 6 feet, with 0.55 per cent for the surface foot.

A comparison of the conditions in selected areas in 1902 with the conditions existing in 1898 showed that the alkali accumulations were becoming more pronounced. This was particularly brought out by a study of sec. 2, T. 1 S., R. 25 E., which had been given special attention in 1898. By using the same method of alkali determination (the electrolytic bridge) it was found just what changes had taken place in the intervening period. In 1898, of the entire section (640 acres) only 186 acres contained alkali in what may be considered injurious quantities, while 454 acres contained some alkali, but not enough to damage crops. In 1902 it was found that the area of land containing much alkali had increased to 506 acres. Again, in 1898 it was found that the greatest concentration of alkali in the first foot of soil did not exceed 1 per cent, and there were only 13 acres containing from 0.60 to 1.0 per cent to a depth of 6 feet, but in 1902 there were 224 acres with from 0.60 to 1.0 per cent and 128 acres containing more than 1 per cent. This is a striking example of the manner in which alkali has continued to accumulate on a given tract of land where no remedial measures had been adopted. In 1906 the alkali conditions were studied again over the entire valley to ascertain the changes, if any, since 1902. It was found that the area affected by alkali had about reached its maximum limit; that is, the increase in land damaged by alkali was very slight in the four years that had elapsed since the survey was made in 1902. This study clearly brought out the fact, however, that the concentration of alkali in the well-defined alkali areas is increasing rapidly. Localities that in 1902 were only slightly damaged by alkali have since been abandoned because the land is no longer capable of producing crops. While this is a serious matter to those owning lands containing alkali, the knowledge that the possible limit of spread has been reached is gratifying for the entire valley.

RECLAMATION OF THE O'DONNELL TRACT.

In 1904 the Bureau undertook the reclamation of a tract of alkali land in the Yellowstone Valley. This was in line with the policy of the Bureau, namely, to establish demonstration experiments in reclaiming alkali land in different areas where a soil survey had clearly defined the alkali problem. The reports made by the Bureau in 1898, as well as in 1902, plainly showed the cause of the trouble and the way of attacking the question, and stated, moreover, that conditions in the valley were very simple as compared with other irrigated districts. In order, then, to demonstrate the principles in reclaiming alkali land, a tract of land 1 mile west of Billings was selected for the experiment. The tract was within easy reach of Billings and near one of the prominent roads of the valley, a location where the progress of the work could be observed by those interested. Pl. I, fig. 1, shows the condition of the land as it appeared when selected by the Bureau of Soils. No useful crops had ever been grown on the land, although one or two attempts had been made a score of years ago. There were many places covered with a thick crust of alkali, while other parts of the tract supported a scattering growth of greasewood, salt grass, and bunches of prickly pear cactus.

In texture the soil varies from a sandy loam to a stiff clay, locally known as gumbo. The clay soil is sticky and difficult to cultivate and so impervious that water percolates through it very slowly. In places at a depth of several feet gravel is found, which is often firmly cemented together and is well-nigh impervious to water. An alkali survey of the tract gave the following results: Fourteen acres, nearly three-fourths of the tract, contained more than 1 per cent of alkali to a depth of 4 feet; 4.2 acres contained from 0.60 to 1.0 per cent, and 1.6 acres carried from 0.40 to 0.60 per cent of alkali. The maximum alkali content was found in the first foot and usually decreased downward. Where the soil consisted of heavy clay the greatest amount of alkali was found. The alkali was typical of that found in other parts of the Billings area. It consisted mainly of sodium sulphate, with smaller quantities of magnesium and calcium sulphate, traces of chlorides, and bicarbonates, but no traces of carbonates. The ground water in midsummer stood within 4 or 5 feet from the surface and carried over 2 per cent of soluble salts.

On account of the large quantities of alkali present and the slow movement of water through the soil a drainage system was considered necessary to achieve marked results within a reasonable time. An outlet was easily secured by digging 660 feet to the drainage ditch that surrounds the city of Billings. The question of securing tiles for the drainage system proved more troublesome. When it was found that no tiles could be purchased near at hand, an effort was made to interest a local brick company in manufacturing tiles. This resulted in the purchase of a tile machine and the contract was awarded to this company. There had always been a small demand at Billings and near-by points for drain tiles and it was believed a much larger demand could be created if the tiles could be sold at much lower prices than those purchased at distant points. By mixing weathered shale with the ordinary brick clay it was found that a satisfactory tile could be made. After making several hundred feet of tiles the tile machine was broken and no further effort was made by the brick company to fulfill their contract. The Bureau was then forced to purchase tiles from Kansas City, Mo., which greatly delayed the installation of the drainage system. The accompanying sketch map shows the general plan of the drainage system on the O'Donnell tract. The drains were placed at an average depth of 4 feet. The fall given the lines of tile was about 3 inches in 100 feet. The slope of the land is to the north and east. On account of the heavy clay subsoil underlying most of the tract, the drains were placed at intervals of 130 feet. The five laterals consist of 4-inch tiles, with silt catchment basins placed 500 feet from the eastern end of each lateral. From the junction of the laterals the outlet drain consists of a box open on the bottom placed at an average depth of 5 feet. Registering weirs were placed at the outlet of the drainage system and at the point where the water-supply canal enters the western end of the tract.

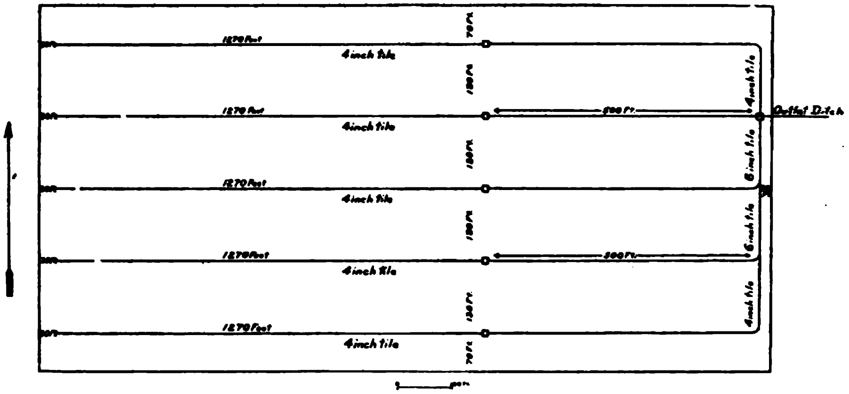

FIG. 2.—Plan of drains, O'Donnell tract.

The cost of installing the drainage system was approximately $35 an acre. This excessive cost was occasioned by the cost of the tiles purchased at a distant point and by the dry compacted clay soils,

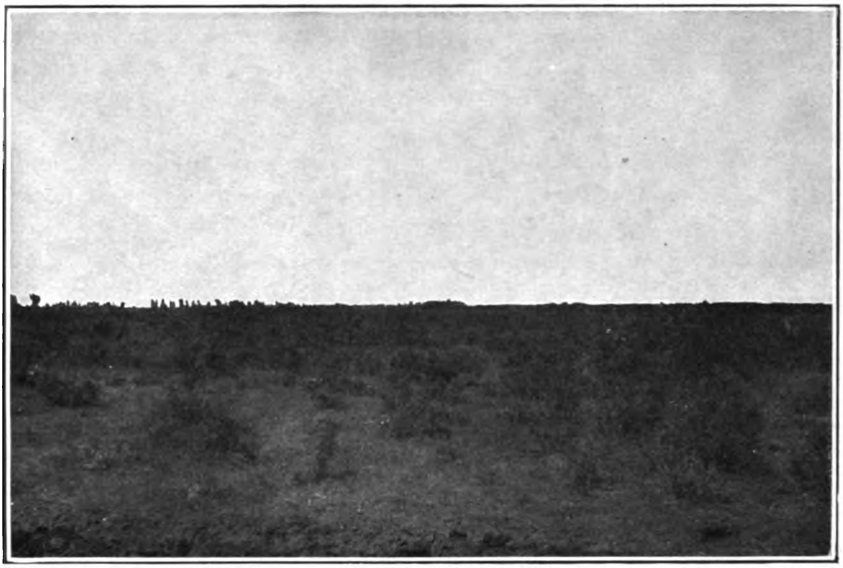

FIG. 1.—SHOWING BARREN ASPECT OF THE LAND INCLUDED IN THE O'DONNELL TRACT BEFORE RECLAMATION.

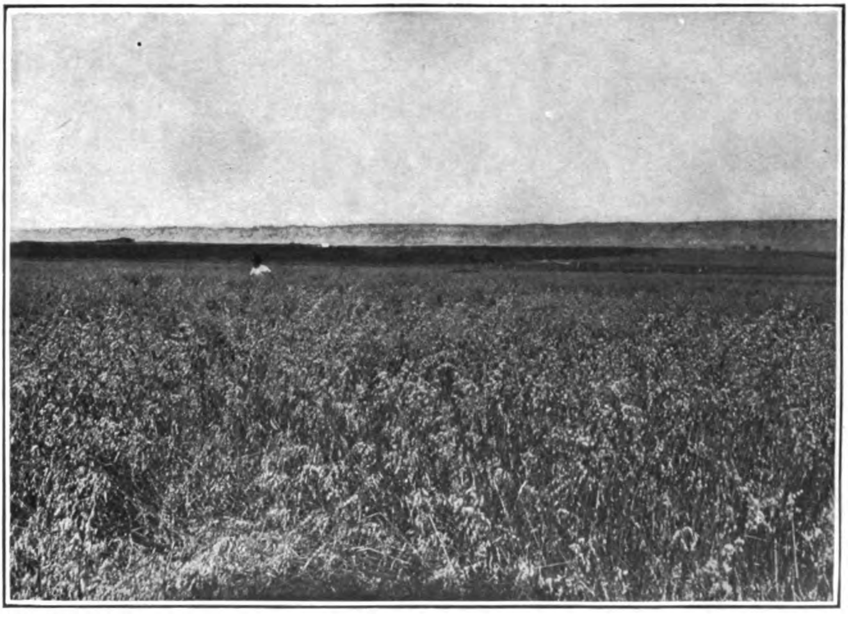

FIG. 2.—SHOWING HEAVY STAND OF OATS ON THE SAME TRACT AFTER ONE YEAR'S TREATMENT BY THE UNDERDRAINAGE-FLOODING METHOD OF RECLAIMING ALKALI LANDS.

which made digging the ditches painfully slow. It is believed that with tiles sold by local factories at reasonable prices and by excavating the trenches, in the spring, when there is more moisture in the soil, the cost of drainage for most of the Billings area will not exceed on an average $15 to $20 an acre. The drainage system was completed too late in the season of 1904 to carry on flooding. The tract, however, was carefully leveled and checks thrown up to hold the water on the land. Fall plowing was also resorted to in order to leave the soil in an open and loose condition so that winter rains and snow might readily enter.

The early spring of 1905 was remarkable for the exceptionally heavy rainfall. It undoubtedly played an active part in effecting the reclamation of the O'Donnell tract. With the beginning of the heavy and continued rains the drains at once responded and by the latter part of June the abnormal rainfall had materially reduced the alkali content of the tract. From early in July until the end of September the tract was submerged practically all of the time. By an adjustment of small supply canals the water was allowed to run night and day and the checks were continually filled. There were two short periods when there was a scarcity of water and the tract was not flooded, but these were not long enough to allow the alkali to accumulate at the surface.

At the end of September, 1905, the soil was allowed to dry and an examination was made to determine the changes that had taken place in alkali content of the tract. It was found that there still remained in the soil only about one-seventh of the alkali that was originally present. An alkali survey made in June, 1905, after the heavy spring rains showed that the maximum alkali content was in the second and third feet, but at the close of the flooding operations in September the maximum was almost uniformly in the fourth foot. During the flooding period sufficient water was used to cover the entire tract to a depth of 6 feet, while the rainfall during this same period was only 1.37 inches; the evaporation was estimated at 12 inches from a free water surface. About one-half of the water used in flooding passed over the outlet weir at the point where the outlet ditch empties into the Billings drainage ditch, 660 feet east of the reclamation tract. A large part of the water undoubtedly passed into the country drainage of the tract or along the line of the outlet ditch. Tests of the drainage water made during the flooding season showed that the soluble salts decreased from 9,000 parts to 3,250 parts per 1,000,000. At the close of the season the tract was plowed and harrowed to overcome as far as possible the bad effects of the continued flooding.

Early in the spring of 1906 the soil appeared to be in excellent condition. The surface indications showed no traces of alkali, except along the north side of the tract, where no flooding had been carried on. An alkali survey showed even less alkali than had been found in September of 1905. In May the soil was disked and harrowed preparatory to seeding oats. The soil responded nicely to this treatment and an excellent seed bed was obtained. Russian side oats were planted May 16 and made rapid growth. A heavy stand was secured that compared favorably with crops sown on alkali-free soils in various parts of the valley. Severe wind and rain storms, however, considerably damaged the crop at the ripening period. The crop was harvested the last of August. Pl. I, fig. 2, shows the appearance of the tract a few days before the crop was cut. The yield was 44 bushels an acre, making the return for the 15 acres amount to $260. Considering that no crops had ever been grown on this land, the results obtained the first year after flooding were very gratifying. They showed conclusively that the removal of alkali had been most thorough and that the land was now in condition to grow any crop adapted to the climatic conditions of the valley.

At the time the crop was removed the tract was returned to the owners. It was the original intention to leave the reclaimed land with a satisfactory stand of alfalfa upon it, but the rapid extension of Billings made the land highly desirable for building purposes. The owners therefore subdivided the tract and sold it for residence purposes, except two lots which were reserved for vegetable gardens.

PRIVATE EFFORT IN RECLAIMING ALKALI LAND.

Prior to 1904, the year in which the Bureau undertook the reclamation of the O'Donnell tract, but little effort was made either to reclaim alkali lands or to utilize them in any way. Generally when the land accumulated sufficient alkali it was abandoned to salt grass and greasewood and valued only for the scant pasturage it afforded. Even during the period when the area of alkali was fast increasing, the farmers, while deploring the injury to their lands, seemed unable to adopt any preventive measures. Many whose lands were ruined moved elsewhere and took up new land, as they could easily do while prices remained low. A few farmers, it is true, tried to cultivate those portions of their farms damaged by alkali by plowing in the fall and seeding to oats the following spring. But the invariable result was that the land did not produce enough grain to pay for cutting and thrashing.

Some few farmers dug shallow ditches to remove the seepage water and some of the alkali, but the ditches were not deep enough and were soon allowed to fill up again, so that no beneficial results were accomplished. Within the last two years, however, considerable progress has been made in taking means to remove alkali from the lands or to prevent conditions from becoming worse. In the summer of 1905 two drainage systems were installed. A bill has also been passed providing for the formation of drainage districts and county officers to look after such matters. By the enactment of this law it is possible for persons owning damaged lands to unite and constructs drains with outlets. Before the passage of this law it was not always possible to do this, as there was no way of securing an outlet through another man's land unless the owner gave his consent. As a result of this law one large district was completed and active steps were taken to form others. In addition to these districts formed under the provisions of the State law, considerable work is being done by groups of farmers cooperating to improve their land. On account of the interest manifested on every side by the farmers in the subject of drainage the prospects are very bright in the Billings area.

With the definite knowledge that alkali is not rapidly encroaching on new good soils and with the question of drainage for the largest areas affected by seepage water and alkali attended to, it now remains for the individual farmer to free his own particular land from alkali. This will require considerable effort, for some tracts of alkali land included at the present time within the drainage districts are situated long distances from the main drains. In a region of sandy subsoils and good underdrainage reclaiming alkali soils may be accomplished with but little effort, but it is unreasonable to suppose that heavy clay soils can be freed from excess of water and alkali by a deep main drain fully one-half mile away. This was clearly proved by the history of the O'Donnell tract reclaimed by this Bureau. The eastern end of this tract was only 660 feet from a deep ditch which had been dug prior to 1898, yet in 1904 this part of the tract contained the greatest quantity of alkali. From this it may be inferred that while the drainage ditch removed the excess of water from this part of the tract and perhaps checked the further accumulation of alkali it did not remove alkali from the upper layers of soil. This was not accomplished until a drainage system had been installed and copious flooding resorted to for several months. And so in many parts of the valley, after the district drainage systems have been constructed, in order to remove any considerable quantity of alkali it will be necessary to provide drainage for individual tracts of land. On the heavy soils having clay subsoils to a depth of several feet it will be advisable to place the drains at a good depth, say 4 or 5 feet, at intervals of about 150 feet apart. After this work has been completed the land should be flooded until it is believed shallow-rooted crops can be grown. For the small field drains tiles may be used in case they can be secured at reasonable prices, or boxes made of boards or planks, or, in case these prove expensive, open ditches will prove effective if cleaned as often as may be necessary.

From the experience of the Bureau on the O'Donnell reclamation tract even the heaviest clay soils of the valley may be freed from alkali by flooding during the irrigating season, after an efficient drainage system has been installed. When the soils contain only moderate quantities of alkali in the areas where drainage districts have been found drainage of individual fields may not be necessary. If some crop that will tolerate some alkali, such as sugar beets, can be started and the soil has fair subsoil drainage each irrigation will remove a certain proportion of the salts, and eventually the field will be entirely reclaimed. Undoubtedly there are many areas in the drainage districts where the conditions of alkali and subsoil drainage are such that the land can be reclaimed in this manner. Deep plowing of the soil and liberal applications of water will materially hasten the reclamation of such tracts, as well as any course of treatment that will check surface evaporation and allow the ready percolation of water through the soil.

SUMMARY.

The soils of the Yellowstone Valley, in which Billings is situated, are mostly heavy loams and clays, which in their natural state contained large quantities of salts, especially in the lower depths. The origin of these salts is in the shales and sandstones, which upon weathering have formed the soils of the valley.

In the early development of the valley the areas visibly affected by alkali accumulations were small and attracted little attention. With extensive irrigation certain tracts of land became wet and swampy, gradually accumulated alkali, and finally were abandoned.

This damage from seepage water and alkali was clearly the result of overirrigation on heavy soils having very poor natural drainage. For a number of years the area of damaged lands spread rapidly, and conditions were considered serious by the farmers of the valley, and many moved to other places rather than combat such unusual and formidable problems.

An examination in 1898 by the Bureau of Soils showed that the deep subsoils were rich in salts, that shallow drains would be ineffectual, and that washing the surface only removed the accumulated alkali from a shallow depth of soil. It was pointed out that underdrainage to be effective must be deep, and that irrigation water should be sparingly used to prevent ruining lands at lower levels. Subsequent studies of the soil and alkali conditions of the valley in 1902 more clearly defined the problems and showed that the area of damaged lands was yearly increasing, and that it was imperative for the farmers to adopt measures to prevent widespread injury to some of the finest tracts of land in the valley.

The experiment in reclaiming a worthless tract of alkali land by deep underdrainage and surface flooding, conducted by the Bureau of Soils, proved successful, and after one year's treatment a good crop of oats was harvested. This work showed the farmers just what steps were necessary to reclaim damaged lands and undoubtedly helped to arouse an interest in the subject.

At the present time the outlook in the valley is most promising, owing to the widespread interest manifested in the formation of drainage districts in the areas most severely damaged by excess of seepage waters and alkali. The State drainage laws make it possible for farmers to construct large drainage systems, and such work is progressing rapidly, while groups of farmers are closely cooperating to the same end.

With the subject of regional drainage so adequately provided for, the reclamation of small farms or individual fields will follow as soon as the farmers appreciate the necessity of further effort in addition to the larger remedial measures that have been adopted. In some cases this will consist of the thorough drainage of fields, using the main drains as an outlet and leaching the alkali from the soil by surface flooding. In other cases careful cultivation and irrigation of crops not especially sensitive may be depended upon to remove the small amount of salt contained in the soil.

In whatever way the alkali soils may be finally reclaimed, the people of the valley are certainly to be congratulated upon their commendable enterprise in so promptly undertaking measures to check the ravages of seepage water and alkali. It is an excellent example and one that should be followed by many other districts in various parts of the West.

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U. S. DEPARTMENT OF AGRICULTURE.

Report No. 71.

SOME MUTUAL RELATIONS BETWEEN ALKALI SOILS AND VEGETATION.

BY

THOMAS H. KEARNEY, Assistant Physiologist,
Division of Vegetable Physiology and Pathology,

AND

FRANK K. CAMERON, Soil Chemist,
Division of Soils.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1902.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Vegetable Physiology and Pathology,
Washington, D. C., June 24, 1901.

Sir: I have the honor to transmit herewith several papers on Some Mutual Relations between Alkali Soils and Vegetation, prepared by Mr. Thomas H. Kearney, of this Division, who was detailed to the work at the request of the Chief of the Division of Soils, and Dr. Frank K. Cameron, of that Division, and respectfully recommend their publication as Report No. 71 of the Department. The studies so far made in connection with the work discussed in these papers have brought to light some important facts and have opened lines of inquiry which promise to develop methods of dealing with alkali soils that will reduce their injurious effects on crops grown where such soils exist.

Respectfully,

Albert F. Woods,
Chief of Division.

Hon. James Wilson,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. **DEPARTMENT OF AGRICULTURE,**
DIVISION OF SOILS,
Washington, D. C., June 24, 1901.

SIR: I respectfully submit herewith the manuscript of a report prepared by Mr. Thomas H. Kearney and Dr. Frank K. Cameron to throw light upon problems encountered by the field parties of the Division of Soils in the soil survey of certain areas in the West affected with alkali. As this is treated largely from the physiological side, it seems proper that it should be transmitted by you for publication.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Mr. **ALBERT F. WOODS,**
Chief, Division of Vegetable Physiology and Pathology.

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SOME MUTUAL RELATIONS BETWEEN ALKALI SOILS AND VEGETATION.

THE EFFECT UPON SEEDLING PLANTS OF CERTAIN COMPONENTS OF ALKALI SOILS.

By THOMAS H. KEARNEY and FRANK K. CAMERON.

INTRODUCTION.

Everyone who is familiar with alkali soils knows that their character varies greatly in different localities, one salt or combination of salts predominating over others which may be present.[1] Sometimes sodium carbonate, the dreaded "black alkali," is relatively abundant as compared with the other soluble soil components. In other cases this salt may be entirely absent or present merely as a trace, while one or more of the "white alkali" salts, e. g., sodium chloride or sodium sulphate, plays the most important part.

It is also known that these salts are not all equally injurious to vegetation. Sodium carbonate, for instance, is generally believed to be much more harmful than any other salt of common occurrence, owing probably to its pronounced corrosive action on the plant tissues. Gypsum, or the dihydrate of calcium sulphate, on the other hand, is harmless and even beneficial in ordinary cases. Experiments with solutions of chemically equivalent strength show very marked differences in the action of different salts upon plant growth. Hence the question whether the salt forming the greater part of the soluble components of a given soil is, to take a concrete case, the very injurious sodium carbonate or the relatively harmless sodium chloride, may often determine whether that soil is utterly useless or quite valuable to the farmer.

It becomes, therefore, a question of great importance to everyone who is concerned with soils which contain an appreciable amount of alkali to know definitely the relative harmfulness of the salts both severally and in mixtures, since the latter is the condition under which they almost invariably occur in nature.

Field observations will give some idea of how the soluble salt components compare in this regard. But the conclusions are necessarily somewhat vague and unsatisfactory; for in the field and under the conditions that are found in nature it is practically impossible to study the effect of any one soil component. It is rare indeed that the "alkali" is composed of but one salt or chemical individual. And, as will be brought out later, it is entirely impossible to predicate anything definite as to the action of a mixture of salts upon a plant from a previous knowledge of the effects produced by each single salt. Conversely, it is equally impossible to draw conclusions as to the action of any one of a mixture of salts from observations of the effects produced by the mixture itself.

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[1] See Bulletin No. 17, Division of Soils, U. S. Department of Agriculture (1901).

The more exact methods of the laboratory are necessary in order to give us precise knowledge, and with this end in view the present investigation was undertaken. It is not claimed that the results so far obtained are in all respects conclusive. The fact that only two species of plants were employed in these first experiments is sufficient indication that they are not. In physiological research nothing is more dangerous than generalization from the behavior of one or a few species of plants to that of plant life as a whole. It is a well-established fact that species differ widely in their reaction to a given chemical or physical condition. Witness the fact that seaweeds will thrive in water containing 1.5 to 3 per cent of sodium chloride, and that salt marshes, whose soil is saturated with water containing nearly or quite as much of this salt, often support a luxuriant vegetation, while the average crop is killed by a much more dilute solution of sodium chloride. Certain plants show a marked aversion to limestone soils, while other species are almost entirely limited to soils having a high content of lime.[1] But it is needless to multiply illustrations of so familiar a phenomenon.

That a similar diversity is manifested by different cultivated crops in their sensitiveness to various mineral salts when present in the soil solutions is well known. Therefore we can not safely predict, until experiments with many different plants have been made, that the order of harmfulness of the alkali salts here established for two plants will be found to hold for all or even many of those which are commonly cultivated in the alkali regions. But, as it is obviously essential to the satisfactory prosecution of alkali soil work that a definite standard for comparison of the salts be established, there need be no further apology for the presentation of these first results of what it is hoped will become an exhaustive investigation.

In the progress of the work numerous data were accumulated which appeared to possess a more than ordinary degree of scientific interest, especially as relating to the chemical theory of the dissociation of electrolytes in solution and to the recently published hypothesis that various salts, or rather their dissociated ions, enter into compounds with the proteids of the protoplasm of plants and animals, which "ion proteids" play a highly important part in life processes and phenomena. This aspect of the subject will be treated particularly in discussing the significance of the experiments with mixed solutions.

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[1] The interesting subject of "lime-loving" and "lime-avoiding" plants has been much discussed by European botanists. It is synoptically treated by Drude (Handbuch der Pflanzengeographie, p. 51) and by Schimper (Pflanzengeographie, p. 105). The latter author gives an extensive bibliography.

METHODS OF EXPERIMENT.

SALTS EMPLOYED.

In the selection of a series of salts for investigation the experience of members of the Division of Soils in field and laboratory served as a guide. Salts were used which have been determined as forming definitely injurious components of alkali soils and as occurring in sufficient quantity to be of practical importance. In about the order of their general abundance in the Western United States these are sodium chloride ($NaCl$), sodium sulphate (Na_2SO_4), sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), magnesium chloride ($MgCl_2$), magnesium sulphate ($MgSO_4$), and calcium chloride ($CaCl_2$). Incidentally, experiments were made with gypsum ($CaSO_42H_2O$), calcium carbonate ($CaCO_3$), calcium bicarbonate [$Ca(HCO_3)_2$], and with magnesium carbonate ($MgCO_3$), and bicarbonate [$Mg(HCO_3)_2$], as well as with an aqueous solution of carbon dioxide (CO_2), the last in order to test a theory that suggested itself during the experiments with carbonates and bicarbonates.

In preparing and standardizing the solutions much assistance was rendered by Mr. Seidell, of the Division of Soils.

The solutions were invariably made with salts manufactured by Baker & Adamson, and found to be practically chemically pure, dissolved in distilled water.[1] They were made up in each case on the basis of a normal solution—i. e., of a gram-equivalent per 1,000 c. c. of solution. In other words, in the case of monovalent compounds, one gram-molecule was contained in a liter of solution, while in the case of bivalent compounds, a half gram-molecule was present.[1] In this way only is a really instructive and fair comparison of the effects of different salts obtainable. Many experiments made in times past in which comparisons were based upon simple percentages of solute to solvent by weight are for this reason of far less value than if normal solutions had been employed. In order to study comparatively those effects produced by different electrolytes which are not dependent upon their respective chemical natures, but which are common to them all and due only to their active masses (such, for instance, as effects due to the osmotic pressure existing in the solution), it is obviously necessary to take into consideration the number of reacting weights of the electrolyte introduced and the amount of electrolytic dissociation which takes place. That is to say, one must consider the concentration of the solution with respect to the number of reacting chemical equivalents, molecules, or ions which may be present. Moreover, attempts to study comparatively the effects produced by different kinds of ions in the solution can only be made by approaching the subject in this manner. But in all statements in this report of the concentration of a given solution both fractions of a normal solution and parts of salt to 100,000 of solution are given in order that the results may be readily intelligible to readers who are familiar with one or the other method, as the case may be.

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[1] The water used in all experiments was distilled through a tin worm and was collected and stored in Winchester quart bottles of practically insoluble glass. A conductivity test showed this to be an unusually pure water, but in order to establish this point beyond doubt, a portion of this same water was redistilled from glass, the first and last portions being of course discarded. A test of the distillate showed it to possess about twice as great conductivity as that which had been distilled only once from the tin. A comparison of cultures of lupines in the water which had been only once distilled with that which was redistilled showed practically no difference in the amount of growth made by the roots. As Galeotti has lately shown [Biol. Centralbl., 21, 329 (1901)], the oligodynamic action of relatively concentrated "colloidal" solutions of metals disappears in the presence of weak solutions of electrolytes. Thus a solution of copper containing 1 gram-atom of metal per 126,000 liters of water produced no effect upon Spirogyra in the presence of a 0.01 per cent solution of sodium chloride, and a solution of 1 gram-atom of copper per 63,000 liters of water acted only after twenty-four hours, although in the absence of the electrolyte the toxic effect of the colloidal copper solution is manifested at a dilution of 1 gram-atom of copper per 126,000,000 liters of water. (See footnote, p. 50.) Hence it is practically certain that in the experiments described in this report no complications were to be feared from the possible presence of a trace of metals in the water used.

The method pursued in these experiments was to make and carefully standardize a large volume of a normal solution of each salt and then dilute to the required strength as occasion demanded.

In beginning the experiments the limit for each salt as determined by investigators in the field was first tried, but immediately showed itself to be too high. So lower and lower concentrations had to be tested until the critical one was reached.

PLANTS SELECTED FOR EXPERIMENT.

For a variety of reasons the white lupine (*Lupinus albus*) was employed in nearly all the experiments, although subsequently alfalfa (*Medicago sativa*) was introduced for comparison. The lupine has a seed of good size, averaging 10 to 12 mm. in greatest diameter. As an abundant supply of nutritive material is stored in the thick seed leaves, there is no danger of starvation of the seedlings in experiments of short duration such as those here described. The lupine seeds germinate readily, sending out a vigorous radicle with clean, bright, white surface. If the seeds are germinated in a proper medium (sphagnum or peat moss saturated with water was actually employed) the root is usually straight or nearly so. These characteristics are important, as they permit the easy and accurate measurement which is essential to a determination of the amount of growth made during a given period. The white lupine has the further advantage of being a favorite subject for experiment with plant physiologists, so that numerous data for comparison are available.

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[1] Dandeno [Bot. Gazette 32, 229 (1901)] has recently called attention to a certain amount of confusion which has existed among both chemists and physiologists as to the preparation of a normal solution, and it has seemed wise to describe in detail the procedure followed in this investigation.

In one series of experiments lupine plants were used which had been grown for eleven days in a prepared culture solution, and had not only developed a considerable root system, but had unfolded two or three leaves in addition to the seed leaves. In these plants all the processes essential to the life of a mature individual were undoubtedly in full activity. As a rule, however, a much earlier stage of growth was preferred, as clearly affording a more sensitive index of the effect of solutions. Experiments with older plants indicated that they are less delicate registers of toxic effect. An additional advantage in using very young plants is that they are practically independent of the substratum so far as food supply (that is, the mineral ash constituents) is concerned, that stored in the thick cotyledons answering all purposes. Consequently the confusion which would unavoidably arise if a culture solution of several salts containing the necessary elements of plant food were introduced is avoided by the employment of seedlings.

Lupine seedlings were transferred directly from the sphagnum, in which they had germinated twenty-four to forty-eight hours previously, to the solution in which the experiment was to be made. In this stage of growth the seed leaves are still closely appressed one to another, and are pale yellow in color. The initial root is 3 to 6 cm. long, and shows as yet no indication of the appearance of lateral branches. Care was taken to keep the moss so wet as to preclude a normal development of root hairs; and in this respect the result would be the same if the radicles had been immersed in water immediately after germination. It was desired to render as slight as possible the change of conditions in transferring from one medium to the other. There is every reason to believe that under these circumstances the amount of injury sustained by the plants as a result of the change of substratum was reduced to a minimum.[1]

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[1] Wolf demonstrated [Landwirthsch. Versuchsst., 6, 203, (1864)] that plants which had been grown in soil until a considerable root system was developed and then shifted to an aqueous solution (as in the experiments of De Saussure and others) could not be depended upon to give as satisfactory results as plants which had been cultivated from the moment of germination in aqueous solutions. But in the case of seedlings transferred from loose wet sphagnum to water before any lateral roots had appeared no difficulty of this sort need be apprehended.

From the experiments of others with plants cultivated in salt solutions it would appear that *Lupinus albus* agrees pretty closely in point of sensitiveness with other large-seeded Leguminosæ, e. g., peas (*Pisum sativum*), beans (*Phaseolus vulgaris*), and, at least in some cases, with the horse bean (*Vicia faba*).[1]

In order to determine how closely plants of the same family correspond in their resistance to toxic effect, and at the same time to obtain data as to the behavior of a plant whose economic importance in arid regions is inestimable, a number of experiments were made with alfalfa (*Medicago sativa*). Here we have to deal with a plant whose seeds are many times smaller than those of the white lupine (1.5 to 3 mm. in greatest diameter). The radicle of the alfalfa seedling is correspondingly small and delicate, and hence requires more careful manipulation than does that of Lupinus. Alfalfa seeds were germinated in wet blotting paper, and were transferred to the solutions when the radicles were 1 to 2 cm. long.

A basis for comparison of the effects of toxic solutions upon plants of very different character and relationship is afforded by Heald's investigations of the action of extremely dilute solutions of hydrochloric acid upon seedling peas, pumpkins, and maize.[2] This author calculates that while one part of hydrogen ions (liberated by dissociation) in 6,400,000 parts of water killed the root tips of the pea (*Pisum sativum*),[3] one part in 3,200,000 was required to produce a similar effect upon the pumpkin (*Cucurbita pepo*) and one part in only 1,600,000 to destroy the root tips of maize (*Zea mays*). In other words, maize offers four times and the pumpkin twice as much resistance to the toxic effect of hydrochloric acid as do peas and lupines.

These results emphasize the importance of extending the present investigations to other plants of as widely different botanical relationship as possible. It is also of great moment that experiments be made with different stages of growth of the same plant, from the germinating seed to some point near maturity. It is as certain that the same kind of plant at various periods of development differs in its reaction to a given salt solution as that the reaction of the same plant to the same solution will be affected by variations of temperature and, perhaps, of illumination.[4]

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[1] But not always, for True [Annals of Botany, 9, 372, (1895)] found the white lupine "more strongly affected by a 0.25 per cent solution than is *Vicia faba* by one of 1 per cent KNO_3 content." He finds Pisum likewise more sensitive than *Vicia faba*.

[2] Bot. Gazette, 22, 136 (1898).

[3] The white lupine appears to be about equally sensitive to H-ions, for Kahlenberg and True [Bot. Gazette, 22, 91 (1896)] determined its limit of endurance in a solution of HCl to be $\frac{1}{6400}$ normal, while later Kahlenberg and Austin [Journ. Physical Chem., 4, 557 (1900)] fixed upon $\frac{1}{5600}$ normal as a more accurate limit.

[4] Storp [Landwirthsch-Versuchsst., 13, 76 (1884)] found zinc sulphate to be extremely injurious to germinating seedlings when exposed to the light, but harmless, or nearly so, in the dark.

The practical value of such a development of these studies is indicated by certain conditions to which agriculture in alkali regions is subject. It is well known that while at the beginning of the season the salt components are often pretty equally distributed through a considerable depth of soil and are in consequence comparatively harmless, the increased evaporation which accompanies increased temperatures and decreased atmospheric moisture as the season advances draws these salts to the surface of the soil, where they often effloresce and form "crusts" (especially in the case of sodium carbonate and sodium sulphate). Hence older plants are frequently exposed to the action of much more concentrated solutions than the same individuals when younger had to contend with. Furthermore, the accidents of irrigation may materially alter the alkali content of a soil in the midst of the growing season of a crop. It is therefore to be hoped that this important extension of the investigation may soon receive attention.

DETAILS OF MANIPULATION.

The manner of preparing the solutions and the plants to be cultivated has already been described. A few words about methods and details followed in the experiments are in order.

To contain the solutions, glass vials nearly 3 cm. in diameter and holding about 70 c. c. of liquid were used. In the experiments with lupines, only one plant was suspended in each vial by means of a hole bored through a close-fitting thin cork stopper, the aperture being entirely closed by means of cotton batting. Protection against undue evaporation from the upper portion of the plant was secured by placing several vials in a glass jar containing a little water and inverting another jar over the whole. The plant was so adjusted in the cork that 1 to 3 cm. of the terminal portion of the radicle was immersed in the solution, the uppermost portion of the radicle extending through the vapor-saturated space between solution and stopper, while the hypocotylary section was invested with moist cotton.

In the case of alfalfa five or six plants were inserted in each vial in the following manner: A piece of aluminum wire was passed through the cork stopper in such a way as to allow it to be raised or lowered at discretion. On the portion of the wire included in the vial five or six small loops were made of proper size to hold in place each a seedling plant, with its seed leaves resting on the loop and its root immersed in the solution.

The duration of the culture in the salt solution was generally limited to twenty-four hours, as it was usually possible at the end of that period to determine accurately whether the root tip had been killed or not. Frequently, however, the plants were returned to the solution for a second period of equal duration in order to remove all doubt upon this point.[1] If at the end of that period no growth had taken place since the first examination, it was regarded as reasonably certain that the root tips had perished, and a less concentrated solution was tried. To obviate the possibility of mistaking a temporary condition of plasmolysis for final loss of vitality the roots were in earlier experiments transferred, after twenty-four hours, from the salt solution to distilled water; but this precaution soon proved to be needless. In all the experiments a control culture in distilled water was maintained under conditions of temperature and illumination identical with those of the salt cultures. As a matter of course, the growth of the roots is by no means as rapid in distilled water as in ordinary river water or in a prepared culture solution.

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[1] In this particular, as in others, the experimental methods outlined by Kahlenberg and True [Bot. Gazette, 22, 87, 90 (1896)] have been followed, as it was desirable to make as close comparison as possible with their results.

It was sought to keep the external conditions as nearly as possible uniform during the entire series of experiments and a temperature of 19° to 21° C. was maintained in the laboratory.[1]

The rate of growth during the period of experiment was ascertained by marking the radicle with india ink just before placing it in the solution. The mark, which was made as fine as was compatible with permanency, was placed at a distance of 15 mm. from the root tip in the case of the lupines and 10 mm. in the case of alfalfa (*Medicago*) so as safely to include the entire zone of active growth in the primary root.[2] This method of measuring the growth of roots was employed by Sachs in his classical studies upon the growth of primary and lateral roots,[3] and has been widely adopted by plant physiologists.[4] By comparison of the marked root with a ruled surface the amount of growth during any given period can be determined with all the accuracy necessary in experiments of the kind here described.[5]

By using a considerable number of individual plants in each experiment with each solution (usually five in case of Lupinus and ten or twelve in case of Medicago) it is believed that the variant due to individual differences in vigor has been practically eliminated.[6]

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[1] In this connection Klemm [Jahrb. f. wiss. Botanik, **28**, 659 (1895)] calls attention to the great variability exhibited by plants as to their limit of endurance in solutions of acids of definite concentration if other external conditions be varied. Askenasy [Ber. deutsch. bot. Gesellsch., **8**, 61 (1890)] describes the effect upon the growth of roots produced by different temperatures or by a variation of temperature during a limited period of time.

[2] Sachs determined the length of the growing portion, in the case of roots of other Leguminosæ, to be 8 to 10 mm. for *Vicia faba* and 3.5 to 6.5 mm. in *Pisum sativum*. [Arb. d. bot. Inst. Würzburg, 1, 413 to 419 (1873); Gesammelte Abhandl., **2**, 803 (1893)]

[3] Gesammelte Abhandl., **2**, 778.

[4] For example, Kahlenberg and True use this method in all their experiments with plants in solutions of toxic substances. [See Bot. Gazette, **22**, 88 (1896)]

[5] Askenasy [Ber. d. deutsch. bot. Gesellsch., **8**, 64, (1890)] shows that this method of marking causes a retardation of growth during the first hour thereafter, but that this is overcome after two hours. Consequently the method could be used without hesitation in these experiments, although it is sometimes attended by disadvantages when the phenomena of growth itself are studied.

[6] More than 2,500 seedlings of *Lupinus albus* and 700 of *Medicago sativa* were employed in the whole series of experiments.

Indeed, that this was the case was pretty effectually shown by several repetitions of the experiments with most of the solutions. It is also indicated by the general regularity with which toxic effect is shown to increase with every increase in concentration of the solution of each salt. By several times repeating experiments with solutions of approximately the critical strength the above-mentioned source of error due to fluctuations in temperature, etc., was likewise reduced to a minimum.

DETERMINATION OF THE LIMIT OF ENDURANCE.

In ascertaining the degree of concentration of a given salt solution which will just permit the root tips to retain their vitality during the period of experiment, one must of course be able to determine also the point at which death definitely occurs. The death point is evidently to be sought far below the degree of concentration which permits no elongation whatever to occur during the period of experiment, for often radicles, of which the marked zone had increased in length several millimeters (even 6) at some time during the experiment, were indubitably dead at the end of twenty-four hours.[1] The mere fact of elongation, irrespective of the time in which it has taken place, does not therefore determine the concentration of a salt solution in which roots will survive, although sometimes useful in ascertaining whether the root is absolutely dead at the end of a given period. It is to the general condition of the apical portion of the root that we must look for a criterion. While it is sometimes difficult to describe those symptoms which denote the death of the root tip, it is comparatively easy to recognize them after one has acquired sufficient experience with the behavior of plants grown in toxic solutions.

One of the most easily detected of the phenomena accompanying death in plants is final loss of turgor due to excessive plasmolysis. In other words, the tissues lose their water, and are unable to make good the loss, even when restored to normal conditions. This is due primarily to a change in the osmotic equilibrium of the plant cells. Ordinarily, through the controlling activity of the protoplasm, a sufficient osmotic pressure is maintained in the sap cavity of the cell to retain the necessary minimum of water. But through various influences, such as exposure of the tissues to a salt solution whose concentration exceeds a certain limit, this power of adjustment may be temporarily lost. In such cases a considerable proportion of the cell water diosmoses through the ectoplasm, and the protoplast in consequence shrinks away from the cell walls, to which it is normally closely applied. If the unfavorable condition persists, this temporary plasmolysis may become permanent, and the cell is killed outright.

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[1] Experiments were made with solutions of a strength known to be fatal, yet permitting some elongation during twenty-four hours. Sodium sulphate (0.05 normal), sodium carbonate (0.02 normal), and magnesium chloride (0.05 normal) were selected, and in every case it was found that elongation ceased entirely after three to five hours. In a water control, on the other hand, growth was still progressing at the end of six hours, and an examination at the end of twenty-four hours showed that it had been pretty equally distributed throughout the entire period. These results as to toxic action correspond with Sachs's statement [Landwirthsch. Versuchsst., 1, 219 (1859)]; Gesammelte Abhandl., 1, 430 (1892)] that "roots appear to lose more and more the power of absorbing water containing salt the longer they are in contact with it."

Such disorganization due to extreme plasmolysis can usually be detected immediately by an examination of the plant tissues with the microscope, and is one of the best indications of death.[1] Roughly, however, injury of this nature is sufficiently indicated after a certain lapse of time by loss of rigidity and elasticity in the plant or part of a plant affected; in other words, it becomes flaccid. If, for example, a root thus rendered flaccid by culture in a salt solution fails to regain its turgor after being transferred to water or to a nutritive solution, it may safely be considered as injured beyond recovery. This was found to be the most satisfactory test of death employed.[2]

The color of the tissues is often a useful symptom of destructive changes. Thus all the sodium salts employed, when given in sufficient amount, decolorized the tissues of the apical portion of the root. This lost its normal brilliant white appearance[1] and assumed a lurid-whitish color. In the case of sodium carbonate (Na_2CO_3) and of sodium bicarbonate ($NaHCO_3$) there occurred a marked clearing of the tissues similar to that produced by the hydrates of potassium and sodium, the root tips becoming nearly transparent. This change is completed long before any loss of turgor is apparent. Magnesium salts (chloride and sulphate) discolored the surface of the roots, producing brownish spots which gradually spread over the whole surface.[2] The difference in character of physiological effect produced by salts of the same acid in the case of sodium on the one hand, and of magnesium on the other, is very great when gauged by these external appearances.

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[1] "The only externally perceptible change [indicating death] is in many cases collapse, a more or less strong, irregular recession of the protoplast from the cell wall, which does not, however, accompany by any means all reactions of substances which occasion death." [Klemm, Desorganisations-erscheinungen der Zelle. Jahrb. für wiss. Botanik, 28, p. 657 (1895).]

[2] Sachs [Arb. bot. Inst. Würzburg, 1, 386; Gesammelte Abhandl., 2, 774] mentions as an indication of the approaching death of the root tip the disorganization of the cells of the root cap, which becomes mucilaginous. This was noted in many cases, but was not found to be a practical test of complete loss of vitality. Another indication of injury to the apical portion of the root is a sharp bend near the tip, which is very different from the normal gentle curvatures. This usually appears where loss of turgor from plasmolysis is not manifested. While indicating injury, this symptom by no means necessarily implies complete loss of vitality and, therefore, does not serve our purpose as a symptom of death. Solutions of a certain concentration of magnesium sulphate, magnesium chloride, and calcium bicarbonate were found to produce this phenomenon in a marked degree. In the case of the salt last mentioned the roots continued to grow slowly in distilled water, during a second period of twenty-four hours. True [Ann. of Botany, 9, 377, (1895)] alludes to these "sharp curves characteristic of injury."

Another means of detecting loss of vitality in protoplasm, to which, however, recourse was not had in the progress of this work, is its coloration when dead by means of nigrosin, which does not color and does not injure living protoplasm. See Pfeffer [Ueber Aufnahme von Anilinfarben in lebende Zellen. Unters. aus d. bot. Inst. Tübingen, 2, 268, 269], who found in experiments with roots of duckweed (Lemna) and with Spirogyra that nigrosin is not absorbed by cells while alive. Living root hairs exposed for three days to a 0.5 per cent solution of this stain assumed no coloration whatever, while hairs after death when similarly treated readily absorbed it.

Another effect produced by some of these salts is an irregular enlargement of a portion of the root. This is very marked in the case of calcium chloride, in a solution of 0.3 normal or thereabouts. The root just above the tip develops a fusiform swelling of which the greatest transverse diameter (2 to 3 mm.) lies 5 to 10 mm. from the apex of the root. A less marked formation of this sort is sometimes produced by magnesium chloride, and even by other salts.[3]

It is well to emphasize once more the fact that the death of the tip of the primary root, and not that of the plant as a whole or even of the entire root, was taken in these experiments as the indicator of the toxic action of solutions. The condition of the distal 10 to 20 mm.

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[1] The "shining white opaque appearance which is characteristic of all healthy roots and which is due to air contained in the intercellular spaces." (Sachs, Landwirthsch. Versuchsst., 1, 216; Gesammelte Abhandl., 1, 427).

[2] Mettenius [quoted by Wolf in Landw. Versuchsst., 7, 202, (1865)] found that these spots, which appear on the roots of both the bean and maize when placed in solutions of magnesium salts, are due to a coagulation of the contents of the epidermal cells, which he did not, however, further describe. Wolf remarks that they do not appear upon plant roots in magnesium salt solutions if a salt of potassium, ammonium, or calcium be present.

[3] Sachs (Arb. bot. Inst. Würzburg, 1, 411, 412; Gesammelte Abhandl., 2, 800) describes swellings of apparently similar character which developed upon roots grown in moist air and watered at long intervals. Wolf [Landw. Versuchsst., 6, 218 (1864)] found that a concentrated solution of potassium sulphate acted in the same manner. "The root tips soon swell in the solution; the form of the root finally resembles that of the root of a tuber-bearing plant. Such swellings arise in particular abundance where lateral roots will break through." The action of a one-fourth per cent solution of potassium nitrate upon roots of *Lupinus albus* as described by True [Ann. of Botany, 9, 374 (1895)] is exactly similar to that of calcium chloride. "Swellings appeared near the tips and the ends tapered suddenly to sharp points. On the other hand, the growth in thickness was much greater than normal, the radicles above the swellings reaching the size of large radicles of *Vicia faba* of the same length."

only was necessarily involved.[1] In the more dilute solutions which are still considered toxic, because destroying the root tip, the proximal portion of the root and the upper part of the plant are often not conspicuously injured by twenty-four or forty-eight hours' exposure. After a certain lapse of time lateral roots are sometimes put forth and grow vigorously in a solution (especially of calcium chloride) which had killed the apical portion of the primary root.

This power of gradual accommodation on the part of the plant to a solution which at first checked its growth and even destroyed the sensitive tissues of the root tip has often been remarked. It is but a step from this to the well-known fact that by gradually increasing the strength of a salt solution in which plants are cultivated they can be made to endure a degree of concentration which would soon be fatal if administered directly.[2] It follows that the limits of endurance here recorded for *Lupinus albus* are merely those of its root tip, selected as being the most sensitive indicator, and are in some cases lower than the limits which would denote death of the plant as a whole. Furthermore, the limit of endurance for the entire plant could undoubtedly be still further elevated by gradually increasing the strength of solution in which the plants are cultivated.

But our present investigation aims merely at a comparison of the relative toxicity of the various "alkali" salts, to attain which the simplest and readiest means are to be preferred. A standard for further comparisons, rather than a thorough investigation of the problem in all its ramifications, is the end of the present paper.

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[1] This was likewise the objective of the experiments of Kahlenberg and True [Bot. Gazette, 22, 88, (1896)]. In order to obtain results closely comparable with theirs, especially as bearing upon the hypothesis of electrolytic dissociation, their mode of procedure has been closely followed in this as in other details. In advocacy of this method of determining toxic action, Professor True writes: "Repeated experiments for years have convinced me that the method used gives the most delicate and easily managed test that I know of for bulky objects like Lupinus roots."

Coupin [Rev. Gén. de Botanique, 10, 177 (1898)] criticises the work of Kahlenberg and True, previously quoted, to the effect that it is impossible to accurately determine the toxic limit of a solution in the short period of experiment (twenty-four hours) allowed by those authors. However, as Professor True observes, it was not the point at which the whole plant succumbs, but that which marks the death of the zone of growth in the primary root, which formed the objective of his experiments. Coupin's method was to grow his plants for several days in the solutions to be tested, taking the strongest solution in which the plant as a whole continued to grow after the first few hours as marking the limit of endurance ("équivalent toxique"). It is obvious, therefore, that no direct comparison is possible between the results obtained by Coupin on the one hand and by Kahlenberg and True, as well as those here recorded, on the other, Coupin's limits of endurance being necessarily much higher.

[2] Thus Stange [Bot. Zeitung, 50, 292 (1892)] found that root tips of *Lupinus albus* and *Phaseolus vulgaris* soon died if exposed directly to a 0.5 per cent solution of potassium nitrate, but by gradually increasing the concentration they could be made to endure nearly 1 per cent without death of the protoplasm.

RESULTS WITH PURE SOLUTIONS.

CONCENTRATION MAXIMUM PERMITTING SURVIVAL OF THE ROOTS.

By applying the methods and tests outlined above it was possible to determine with a reasonable degree of accuracy the limit of concentration for each of the salts in pure solution in which the root tips of young seedlings of white lupine could just survive. It is believed that, like conditions being maintained and the same plant in the same stage of development being used, the limits will not be materially altered by further experiment. Moreover, it is regarded as not improbable that the salts will be found toxic in about the order stated below if other plants or other stages of growth of the same plant be tested with them. The limit of endurance in a solution of each particular salt will doubtless be higher or lower for different objects, but the general sequence of harmfulness should remain practically unaltered, so far as the higher plants are concerned. Experience alone can demonstrate the correctness of this assumption.

The limit of concentration permitting roots of white lupine to retain their vitality during twenty-four hours is, for each of the more important readily soluble "alkali" salts, as follows, the limit being stated both in parts of salt per 100,000 of solution and in fractions of a normal solution:

TABLE I.—*Results of experiments with pure solutions.*

Name of salt.	Degree of concentration.	
	Parts per 100,000 of solution.	Fractions of a normal solution.
Magnesium sulphate	7	0.00125
Magnesium chloride (1)	12	.0025
Sodium carbonate	26	.005
Sodium sulphate (2)	53	.0075
Sodium chloride (3)	116	.02
Sodium bicarbonate (4)	167	.02
Calcium chloride	1,377	.25

NOTES.—(1) With magnesium chloride the limit of endurance (for the whole plant), as determined by Coupin [Rév. Gén. de Bot., 10, 188 (1898)], is 0.8 per cent, while with magnesium sulphate the limit is 1 per cent, thus reversing the order of toxicity for the two salts as given above. Wolfe (Landw. Versuchsst., 6, p. 214) notes the strongly toxic effect of magnesium solutions upon roots of bean and maize. The brown coloration of the surface of the radicle, induced by these salts, appeared a few hours after immersion. Wolf's suggestion that the very poisonous effect of magnesium sulphate may be due to the decomposition of the salt by excretions of the roots can not be regarded as possessing great probability. His experiments, which were designed primarily to ascertain the volume of water absorbed by the plant from solutions of various salts of different concentration, are considered by him to indicate that the cell wall [ectoplasm] is less permeable to sulphates than to other salts (l. c., p. 217). Loew (Bul. No. 18, Div. Veg. Phys. and Path., p. 42) found that Spirogyra died after four or five days of immersion in a 0.1 per cent solution of magnesium sulphate, but remained alive for a long period in equivalent solutions of sulphates of potassium, sodium, and calcium. Similarly a 1 per cent solution of magnesium nitrate killed a smaller Spirogyra in six to twelve hours, while the nitrates of potassium, sodium, and calcium, in solutions of corresponding strength, did not destroy the plant. The peculiarly poisonous action of salts of magnesium described by Loew is explained by him on the hypothesis that calcium forms intimate compounds with proteids, and that these are essential to the organization and life of the cell-nuclei and chloroplasts of the higher plants. Consequently, if magnesium is supplied without calcium to plants, especially in the form of readily soluble salts, such as chloride, nitrate, and sulphate, the acids of the magnesium salts would be attracted by the calcium which formed part of the nuclear proteid compounds. The latter would consequently be disorganized, magnesium being unable to take the place of calcium in proteid compounds without fatal disturbances of equilibrium in the cell. As evidence for this hypothesis is adduced the corrective effect of the addition of lime to either soils or culture solutions in which plants are suffering from magnesium poisoning, and the further fact that plants suffer less in culture solutions from which both calcium and magnesium are absent than in such as contain magnesium but no calcium. It must be observed, however, that the chemical rationale of this theory rests upon the assumption that calcium is a stronger base than magnesium, and will exert a greater attractive force upon acids, while it ignores the application of the mass law to the distribution of an acid between two bases, which itself accounts very satisfactorily for the facts observed.

(2) Of sodium sulphate Wolf (Landw. Versuchsst., 6, pp. 210, 213) indicates that solutions of more than 0.05 per cent are toxic to roots of the bean (*Phaseolus vulgaris*). Loeb [Am. Journ. Physiology, 3, 393 (1900)], found sodium sulphate to be more poisonous than sodium chloride to eggs of a fish (*Fundulus heteroclitus*). This he attributes to a precipitation of calcium from its ion proteid compounds in the protoplasm, a reaction effected through the sulphions dissociated by sodium sulphate.

(3) The minimum toxic concentration for sodium chloride, the same plant and the same methods being used, is placed about three times as high (one-sixteenth normal) by True [Amer. Journ. Sci., ser. 4, 9, 187 (1901)]. As the experiments with sodium chloride here described were repeated several times, without variation in the result, no explanation for this discrepancy is apparent.

Many experiments have been made with sodium chloride as to its effects upon plants. It may be of interest to refer to some of those in which limits of endurance have been determined, especially as these are in all cases much higher than that given above for root tips of *Lupinus albus*. Storp [Biedermann's Centralbl., 13, 76 (1884)] found that sodium chloride in a solution of greater concentration than 0.01 per cent retarded the germination of seeds. Eschenhagen [Ueber den Einfluss von Lösungen verschiedener Concentrationen auf den Wachsthum der Schimmelpilze (1889)], quoted by Stange in Bot. Zeitung (1892, p. 255), gives the following limits for the active growth of fungi in solutions of sodium chloride and of sodium nitrate:

Fungus.	Per cent sodium chloride.	Per cent sodium nitrate.
Aspergillus	17	21
Penicillium	18	21
Botrytis	12	16

Richter [Ueber die Anpassung der Süsswasseralgen an Kochsalzlösungen Flora, 75, 4 (1892)] found that *Zygnema stellinum genuinum* lived two months in a 6 per cent solution of sodium chloride added to a culture solution, and more than a year when the sodium chloride solution was 2 per cent or weaker. De Freitag [Archiv für Hygiene, 11, 68 (1890)] is authority for the statement that *Bacillus tuberculosis* lived three months, and the typhus Bacillus six months in a saturated solution of sodium chloride. Coupin [Révue Gén. de Botanique, 10, 177 (1898)] obtained the following limits for various plants in solutions of sodium chloride:

Plant.	Per cent limit of endurance.	Per cent in different solution.
Wheat	1.8	0.5
Peas	1.2	.25
White lupine	1.2	----------
Maize	1.4	----------
Vetch	1.1	----------

According to W. Sigmund [Landw. Versuchsst., 47, 1 (1896)] the maximum concentration of NaCl solutions endurable by germinating seeds of cereals is 0.5 per cent, of legumes 0.3 per cent, of rape 0.1 per cent Loew [Bul. 18, Div. Veg. Phys. and Path., p. 19] found that Spirogyra suffers in a solution containing 0.5 per cent of sodium chloride.

(4) Carbonic acid (HCO_3) is here regarded as a monovalent acid, so that a gram molecule (instead of one-half of a gram molecule) to the liter has been used in making up normal solutions of sodium bicarbonate. To prevent inversion to the normal carbonate (Na_2CO_3) [see Cameron and Briggs, Bul. 18, Div. of Soils, 1900; also Jour. Physical Chem., 5, 537 (1901)] solutions of the bicarbonate were always well charged with carbon dioxide and were tested for hydroxyl with phenolphthaleine before being used in culture experiments, and again at the end of the experiment. It is quite possible, of course, that a small error was thus introduced, as the carbonic acid formed by the dilution of carbon dioxide in water may have retarded somewhat the dissociation or ionization of the sodium hydrogen carbonate. It is improbable that sodium hydrogen carbonate, unaccompanied by the normal carbonate, would ever occur in nature except in the presence of an excess of carbon dioxide, which fact is a further justification of the procedure here described.

In order to demonstrate that this excess of carbon dioxide was not in itself injurious to the roots of white lupine, the following simple check experiment was made: Carbon dioxide was forced into distilled water until a saturated solution was obtained. Plants were then entered in this solution, which was protected as completely from loss of carbon dioxide as circumstances would permit. After twenty-four hours the solution was tested with barium hydrate, and the heaviness of the resulting precipitate of barium carbonate showed that very much more carbon dioxide still remained than is present in ordinary water. During this period the roots grew nearly as well as in water containing only the normal quantity of carbon dioxide. It might be supposed that a solution of carbon dioxide in water and presumably containing the hypothetical carbonic acid must needs be itself quite toxic, as it would be expected to yield the hydrogen ion which recent investigations have shown to be excessively toxic. In this connection some work of Pfeiffer [Ann. Chem. (2), 23, 625 (1884)] will prove interesting. This investigation showed that a solution of carbon dioxide is an exceedingly poor conductor; that in fact the highest conductivity observed in such solutions was only about a thousandth of that which Kohlrausch's work showed it should possess. See also Knox [Ann. Phys. Chem., 54, 44 (1895)] and Walker and Cormack [Journ. Chem. Soc., 77, 5 (1900)].

It would seem rational, therefore, to consider that carbonic acid does not exist itself, or at least in only minute quantities in solutions of carbon dioxide, but is *potentially* present in its constituents and only forms in the presence of some added influence, such as a base. And that, therefore, even a concentrated aqueous solution of carbon dioxide would contain no hydrogen ions, or so very small a quantity as to be ineffective against so delicate an indicator as a plant root.

Experiments to ascertain the limit of endurance in pure solutions were also made with seedlings of alfalfa (*Medicago sativa*). Although absolute limits for this plant have not, as yet, been determined, they appear to be somewhat lower for every salt than in the case of *Lupinus albus*, but more than one-half as high. Thus for magnesium sulphate the limit appears to lie between 0.000625 and 0.00125 normal, while for magnesium chloride the limit will be found between 0.00125 and 0.0025 normal.

A glance at the preceding table shows very clearly that it is the basic rather than the acid radicle of the salts used which chiefly determines their relative toxicity. In other words, the cathions derived from these salts are very much more active in their effect upon plant tissues than are the anions. This is strikingly brought out by a comparison among themselves of the three chlorides of magnesium, sodium, and calcium, on the one hand, and of the chlorides and sulphates of magnesium and sodium, respectively, on the other. In the former case, although the anions (Cl) are identical in kind we find magnesium chloride eight times as toxic as sodium chloride, and one hundred times as toxic as calcium chloride. In the latter case, magnesium sulphate is only twice as toxic as magnesium chloride, while sodium sulphate is little more than two and one-half times as injurious as the corresponding chloride.

The results with salts of magnesium, as compared with those of sodium, confirm the results obtained by W. Wolf, Loew, and others as to the strongly poisonous qualities of the former base.

All four of the salts of sodium with which experiments were made are widely distributed and often very abundant in the alkali regions of the western United States. As was to be expected, sodium carbonate or black alkali was found to be the most harmful of these, but it is not much more injurious than sodium sulphate. That the latter is much more poisonous than sodium chloride is a result not altogether anticipated at the beginning of the investigation.[1] As was predicted, sodium bicarbonate proved to be somewhat less toxic than sodium chloride.[2]

As a matter of fact, the limit of endurance in a solution of sodium bicarbonate is not much higher in parts of salt per 100,000 of water and is no higher in fractions of the reacting weight than it is for sodium chloride. It should be mentioned, however, that the plants survive in a solution of the bicarbonate of the strength given in the table in much better condition than in the corresponding concentration of the chloride, so that the latter must be regarded as the more harmful of the two salts. The wide distribution of sodium bicarbonate and its abundance as a component of many alkali soils renders the demonstration of its marked poisonous effects upon vegetation, even when present in comparatively dilute solutions, a matter of no little importance. Although much less injurious than is the normal carbonate or "black alkali," the presence of this salt can not be neglected in future estimations of the value of western soils.

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[1] Stewart [Ninth Ann. Rep. Utah Agr. Exp. Sta. p. 26 (1898)] found sodium chloride more injurious than sodium sulphate to germinating seeds of legumes and cereals.

[2] Very different results from these here recorded as to the relative toxicity of the carbonate and bicarbonate of sodium were obtained by Coupin [Rév. Gén. de Botanique, 12, 180 (1900)]. Experimenting with seedlings of wheat, this author found that the least concentrated fatal solution ("équivalent toxique") is 1.1 grams per 100 of water for sodium carbonate, while for the bicarbonate it is 0.6 gram. Hence the latter would be twice instead of one-fourth as poisonous as the former. Sigmund [Landw. Versuchsst., 47, 2 (1896)] found that while Na_2CO_3 at a concentration of 0.5 per cent killed germinating seedlings of vetch and rape and retarded the development of wheat seedlings, $NaHCO_3$ at the same concentration was harmless.

An explanation of the harmful action of sodium bicarbonate which at first suggested itself was that by its dissociation free hydrogen ions are liberated, though the weight of evidence on chemical grounds is rather against this view.[1] It has been shown by recent investigators[2] that it is probably the hydrogen ions dissociated by certain acids (especially the strong mineral acids) which make them so injurious to organisms, even in extremely dilute solutions. If this were the reason for the toxicity of sodium bicarbonate it would follow that water heavily charged with carbon dioxide, as in the check experiment described above (p. 20), would prove similarly injurious to plant roots by reason of the dissociation of hydrogen ions by the carbonic acid (HCO_3), which is supposed to be formed when carbon dioxide is dissolved in water. But, as has already been noted, no toxic effect was obtained with an aqueous solution of carbon dioxide.[3]

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[1] Walker and Cormack, Journ. Chem. Soc., **47**, 5 (1900) and Bodländer, Zeit. für physik. Chem., **35**, 25 (1900).

[2] Kahlenberg and True, Bot. Gazette, **22**, 87 (1896); Heald, l. c., p. 184; Loeb, Pflüger's Archiv f. die gesammte Physiologie, **69**, 4 to 9 (1898); Kahlenberg and Austin, Journ. of Physical Chem., **4**, 553 (1900); True, Amer. Journ. Sci. ser. 4, **9**, 183 (1900).

[3] There exists among plant physiologists some diversity of opinion as to the direct effect of large quantities of carbon dioxide upon the growth of roots. The subject is evidently one which needs a more thoroughgoing investigation, not only from a scientific standpoint, but from economic reasons also, as it is intimately connected with tillage and drainage problems. For an extended discussion of this question see Lopriore in Jahrb. für wiss. Botanik, **28**, 531 (1895). The author mentions that Boehm found roots of the bean (*Phaseolus vulgaris*), when exposed to an excess of carbon dioxide, to be shorter, and the lateral roots fewer, than is ordinarily the case. Jentys [Bul. Internat. Acad. Sci. Cracovie, 1892, 306 (1893)], found that by passing atmospheric air to which had been added 4 to 12 per cent of carbon dioxide through the soil of culture pots, an injurious effect upon the roots of the bean and the yellow lupine could be detected, although the injury was less than in Boehm's experiments. On the other hand, wheat was practically unharmed. Lopriore (l. c., p. 623), concludes that carbon dioxide in excess has a hindering but not a permanently injurious influence upon the functions of protoplasm. This effect is not ascribable to the absence of oxygen, but is specific. Plant cells can gradually accommodate themselves to a quantity of carbon dioxide, which, if applied directly, would injure them. Lopriore's experiments were made chiefly with Mucor, yeast, and pollen grains and tubes.

As there is probably but a small difference in the amount of sodium ions yielded by sodium chloride and by sodium hydrogen carbonate, at the dilutions here involved, the difference in their toxicity observed must in all probability be ascribed mainly to the anions.

It is likely that the great toxicity of normal sodium carbonate is largely due to the hydroxyl ions resulting from the hydrolysis of this salt. In the case of the bicarbonate of sodium in all the experiments involving its use, and described in this paper, hydrolysis was avoided by dissolving carbon dioxide in the solution in amounts sufficient to prevent any inversion to the normal carbonate, a reaction which would necessarily result were hydrolysis of the bicarbonate permitted.[1] Since it seems reasonably certain that HCO_3 ions are not toxic, the toxic influence of the sodium bicarbonate solutions could be safely attributed to the sodium ion alone were it not for the fact that toxic solutions of this salt produce the peculiar "clearing" effect upon plant tissues which is well known in the case of the normal carbonate of sodium and of the hydrates of potassium and of sodium. This effect is very different from that caused by other salts of sodium, e. g., the sulphate and the chloride.

Calcium chloride was found to be ten times less injurious than is sodium chloride. For this reason, and because it rarely predominates in areas of any considerable size, this salt can not be regarded as, under ordinary circumstances, a dangerous component of alkali soils. As we shall presently see, there is reason to believe that it can in many cases be a highly beneficial component of the soil.

Attention should be directed to the fact that the figures given in the above table represent only approximate results, the determination of the absolute limit for each salt depending theoretically upon the testing of an almost infinite number of concentrations. Thus, as a rule, solutions of a concentration of 0.2, 0.15, 0.1, 0.075, 0.050, etc., normal were employed, although more numerous intermediate concentrations, e. g., of 0.2000, 0.1825, 0.1750, etc., normal could have been tested. However, it is doubtful whether the reaction upon plant tissues of finer differences could be detected, and it is believed that for all practical purposes a sufficient number of concentrations was used. As has already been noted, the limits of endurance in the case of different salts are not of precisely equal value, the roots not surviving in all in exactly the same condition. Thus roots which survived after twenty-four hours in a 0.005 normal solution of sodium carbonate presented a perfect appearance and grew vigorously in distilled water during a subsequent period of twenty-four hours. On the other hand, roots which endured a 0.25 normal solution of calcium chloride presented a markedly abnormal aspect at the end of twenty-four hours, and made little subsequent growth when transferred to water. Likewise roots survived in better condition in 0.0075 normal sodium sulphate than in 0.02 normal sodium chloride solution. It was found much easier to determine sharply the limit of endurance for sodium carbonate and sodium bicarbonate than for other salts, as in 0.005 and 0.02 normal solutions of the two carbonates, respectively, all, or nearly all, roots survived in apparently perfect condition, while in 0.0075 and 0.025 normal, respectively, all roots were killed and symptoms of advanced disorganization were apparent after twenty-four hours.

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[1] See paper on Equilibrium between Normal Carbonates and Bicarbonates in Aqueous Solutions, Cameron and Briggs. Bul. 18, Div. Soils, U. S. Department of Agriculture (1901); Jour. Physical Chem., 5, 537 (1901).

CONCENTRATION MINIMUM PROHIBITING ELONGATION OF ROOTS.

A comparison of the seven salts above enumerated in regard to the degree of concentration of each in which absolutely no elongation of the roots occurred during twenty-four hours is interesting, as illustrating how far this point is removed from that of the minimum concentration which is still toxic. It will be seen that the position of the salts in this scale does not at all correspond with their sequence in the table of limits of endurance. In many cases, especially when the solution was still more concentrated, not only no increase of length but a positive shrinkage of 0.5 to 2 mm.[1] was detected.

TABLE II.—*Concentrations which absolutely prevent growth.*

Name of salt.	Concentration of solution.	
	Parts per 100,000 of solution.	Normal.
Sodium carbonate	280	0.05
Sodium bicarbonate	417	.05
Magnesium chloride	960	.2
Sodium chloride *a*	1,160	.2
Sodium sulphate	1,410	.2
Calcium chloride	1,652	.3
Magnesium sulphate	1,680	.3

a According to Pfeffer (Pflanzenphysiologie, Ed. 2, 1, 414) a culture solution to which enough potassium nitrate or sodium chloride is added to render it isosmotic with a 2 per cent potassium nitrate or 1.7 per cent sodium chloride solution causes a cessation of growth in ordinary plants while an increase to 3 per cent is necessary to prevent growth in halophytes.

It is impossible to reconcile this sequence, as compared with that of Table I, with the notion, which still appears to find advocates, that the injurious effect of these salt solutions is merely a function of their osmotic pressures. If any fresh evidence were needed to disprove this assumption it is afforded by the fact, very clearly brought out in the present investigations, that marked toxic effects frequently appear long before loss of turgor has manifested itself or cessation of growth has occurred. It is certain that no useful conclusions as to the degree of toxicity of a solution can be drawn from its osmotic pressure.

True [Bot. Gazette, **26**, 407 (1898)] calls attention to the difficulty of distinguishing the purely chemical from the merely osmotic (plasmolyzing) effect of a salt solution. He experimented with Spirogyra in order to obtain means of making such distinction, comparing its behavior in a solution of cane sugar, which is believed to possess no chemically toxic properties, with that in solutions of sodium chloride and potassium nitrate. The maximum concentration of the sugar solution in which life could be maintained was determined to be 0.75 normal. Allowing for differences of dissociation, 0.46 normal should then be the maximum endurable concentration of a sodium chloride solution if only its osmotic pressure were involved. In fact, however, 0.1 normal was found to be the actual limit, so that a definite toxic action of sodium chloride must be admitted (loc., cit., p. 410).[1]

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[1] In some solutions this loss of length due to plasmolysis was as great as that found by Sachs in roots which were exposed for thirty minutes to the dry air of a room. (Arb. bot. Inst. Würzburg, **1**, 396; Gesammelte Abhandl., **2**, 784, 785.)

Were the injurious action of these solutions attributable to plasmolysis alone, an approximately equal amount of elongation should take place in solutions of different salts, if each solution contain an equal fraction of a gram equivalent to a given amount of water, granting that the dissociation of each salt was equally great at the given concentration, as would be approximately true for strong electrolytes at the concentrations here used; for elongation and growth in general are intimately connected with the turgor conditions of the tissues,[2] which, in turn, depend upon the osmotic force exerted by the surrounding solution. That force being equal for each of two solutions, the turgor and the amount of elongation of the roots immersed in each should also be equal if osmosis were the only factor involved. That this is not the case is sufficiently established by the figures given in Table II.

RESULTS WITH LESS SOLUBLE SALTS.

Besides the easily soluble alkali salts a few others were used in experiments, i. e., calcium sulphate [$CaSO_4$] calcium carbonate [$CaCO_3$], calcium bicarbonate [$Ca(HCO_3)_2$], and the carbonate and bicarbonate of magnesium [$MgCO_3$ and $Mg(HCO_3)_2$]. These were found to be either toxic in a very slight degree, indifferent, or positively stimulating to growth.

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[1] From True's results it is clear that at the concentrations involved in our experiments with pure solutions the toxic effect observed must in every case be referred to action of a chemical rather than a purely physical nature. In some of the mixed solutions, such as the very concentrated ones containing calcium sulphate, it may be that their osmotic pressure determines the limit of endurance of the plant roots.

[2] For example that, except perhaps in rare instances, growth can not be resumed after an interruption (such as is occasioned by transference of plants from one medium to another) unless the turgor of the plant or the organ concerned is nearly or quite normal, was shown by Curtis [Bul. Torr. Bot. Club, 27, 1 (1900)] in the case of mycelia of Mucor, Botrytis, and Penicillium, grown in a plasmolyzing solution (4 per cent potassium nitrate). As this author expresses it, "there is a necessity of a certain turgor force before growth is possible, and growth can not occur until a turgor pressure has been reached which is normal to the plant growing in the given solution." (Loc. cit., p. 11.)

In a (necessarily dilute) solution of gypsum, which contained a considerable quantity of the undissolved salt in suspension, the plants grew decidedly more vigorously than in pure water.[1]

In a saturated, but necessarily very dilute, solution of normal calcium carbonate [$CaCO_3$], roots of Lupinus elongated nearly twice as much and remained in decidedly better condition during twenty-four hours than in distilled water. This solution gave a faint reaction for hydroxyl (with phenolphthaleine) at the beginning of the experiment, but none at the end of twenty-four hours, doubtless because of the production of carbonic acid through the excretion of carbon dioxide by the roots. But a solution of calcium bicarbonate [$Ca(HCO_3)_2$], made by saturating a portion of the same calcium carbonate solution with carbon dioxide, permitted only about one-third as much growth of the roots as took place in distilled water. Their condition was decidedly abnormal at the end of twenty-four hours, even the turgor being poor.[2]

Magnesium carbonate [$MgCO_3$], in a solution which gave a strong hydroxyl reaction with phenolphthaleine, allowed the roots to grow about as rapidly as in distilled water and to remain in about normal condition. On the other hand, a portion of the same solution to which an excess of carbon dioxide was added and in which no free hydroxyl could be detected (either before or after the experiment) exerted a strongly toxic action upon the roots. These made practically no growth during twenty-four hours; their turgor became decidedly inferior, and there occurred a marked discoloration of brownish spots, such as is produced by the readily soluble magnesium salts. Here it is obviously a case of a greater amount of magnesium in solution, owing to the presence of carbon dioxide in excess.[1] Why the corresponding calcium solution should also hinder growth can not be satisfactorily explained at present.

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[1] The stimulating effect which lime often exercises upon the growth of plants is too well known to require illustration. The presence of calcium salts in considerable quantity leads to a more vigorous production of root hairs than is normally the case, as can easily be demonstrated by culture experiments, in which only the tip of the root is immersed in the calcium salt solution. On the surface of the root above the solution a great number of unusually long root hairs appear. To this effect of the presence of lime, and the consequent readier absorption of potassium and ammonium salts from the soil, Loew attributes in part the benefits obtained by liming. (Bul. No. 18, Div. Veg. Phys. and Path., U. S. Department of Agriculture, p. 43.) That calcium salts directly stimulate growth, apart from the production of root hairs, is, however, shown by cultures with the root entirely immersed in an aqueous solution, thus precluding any important development of these organs.

[2] Schloesing's investigations [Comptes rendus, 74, 1552 (1872)] showed that 100,000 parts of pure water, i. e., free from dissolved carbon dioxide, would dissolve about 1.3 parts of calcium carbonate. Treadwell and Reuter [Zeit. für anorg. Chem., 35, 28 (1900)] showed that by increasing the pressure of the carbon dioxide in the gas phase in contact with the solution until it was one atmosphere, the solubility was increased so that 100,000 parts of water would dissolve 116 parts of calcium carbonate. Even at this extreme solubility there would be but 46 parts of calcium per 100,000 of water, as against about 60 parts in a saturated solution of calcium sulphate, in which plants thrive well.

RESULTS WITH MIXED SOLUTIONS.

Upon comparing the limits of endurance for lupine roots in pure solutions of the "alkali" salts with the limits determined by the methods employed in a field survey, it became obvious that the former were vastly lower than the latter; and that furthermore the order of toxicity of the several salts as fixed by investigators in the field differed greatly from that obtained by experiments in the laboratory. This was strikingly the case with magnesium sulphate, which is decidedly the most toxic of the seven salts when alone in a pure aqueous solution, but which is regarded as the least injurious by students of alkali soils. But it was recalled that none of these salts usually occurs in any notable quantity in the soil save in the presence of one or several others, both of the readily soluble salts and of the comparatively insoluble magnesium carbonate, calcium carbonate, and calcium sulphate. The key to the discrepancy appeared therefore to lie in mixtures of the various salts, and the study of these became, logically, the next step in the investigation.

In experimenting with mixed solutions it was planned to test every possible combination of two of the readily soluble salts with which experiments were made in pure solutions. Another line of experiments, from which were obtained results which are believed to be of considerable scientific interest and from an economic point of view to indicate one of the possible solutions of the alkali soil problem, consisted in combining each of the readily soluble salts with each of three difficultly soluble ones—calcium sulphate, calcium carbonate, and magnesium carbonate. The only triple mixtures so far tried are those of each readily soluble salt (except calcium chloride) with calcium sulphate and calcium carbonate. Sodium bicarbonate was tested only in this triple mixture.

Although the work with mixtures of salts is by no means completed, the data thus far obtained throw so much light on the whole subject of alkali soils, and go so far to account for the fact that the limits of endurance of plants in pure solutions of the various salts are low as compared with those determined from the observations of survey parties in the field, that it seems advisable to present them here.

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[1] Treadwell and Reuter [Zeit. für anorg. Chem., 17, 199 (1898)] showed that at 15° C. and under a partial pressure of carbon dioxide in the vapor phase equal to zero, pure water dissolves about 63 parts of magnesium carbonate per 100,000. With a partial pressure of carbon dioxide in the vapor phase equal to one atmosphere there was dissolved about 1,211 parts magnesium hydrogen carbonate, equivalent to 698 parts of the normal carbonate per 100,000 of solution. It is thus seen that the solubility is enormously increased by the presence of carbon dioxide. Cameron and Briggs [Bul. 18, p. 22, Division of Soils, U. S. Department of Agriculture (1900)] showed that a solution of magnesium carbonate in solution in equilibrium with ordinary air contained about 18 parts of magnesium in 100,000 of solution, which might have been expected to be enough to prohibit growth in view of the toxicity of solutions of magnesium chloride and magnesium sulphate. It should be further noted that it was shown that 6 parts of the dissolved magnesium was combined as the normal carbonate, so that the solution contained more than appreciable-amounts of OH ions, resulting from the hydrolysis of this latter salt.

In the case of mixtures of two readily soluble salts, solutions of each, of twice the desired concentration, were mixed in equal volumes. Where one of the salts is a comparatively insoluble one, it was added in solid form to a solution of definite concentration of the soluble one, and the mixture was then diluted to the required concentration, as though the more soluble salt alone were present. (The source of error incurred by this method was considered so slight as to be practically negligible.) The mixture was then allowed to stand for a week or ten days with frequent shaking, in order to bring it to equilibrium before using. In all mixtures of magnesium carbonate and of calcium carbonate alone with other salts, the undissolved residue was removed by filtration. Likewise in earlier experiments with calcium sulphate added to other salts, the residue was removed, but in those upon which are based the limits given in the tables it was retained. In all cases where both calcium sulphate and calcium carbonate were added, the undissolved residue remained during the culture. The difference in limit due to the presence or absence of a solid excess was, however, usually imperceptible, and always slight.

In every case the object was to ascertain how far the limit of endurance for the roots in the presence of the more toxic salt could be raised by addition of one that is less injurious. Although the concentration of solution of the latter is invariably stated, if it be a readily soluble salt, it is the concentration of solution of the more poisonous salt as denoting a corresponding limit of endurance to which attention is chiefly directed. It is interesting that in cases where both of the salts mixed are readily soluble ones the less toxic salt appears usually to be more effective in neutralizing the more toxic one when added in concentration somewhat above rather than below that in which plant roots will endure it when alone. Thus, in a mixture containing equal volumes of 0.0075 normal sodium carbonate and 0.01 normal sodium sulphate, roots of two plants survived, but all died when the mixture contained 0.0075 normal sodium carbonate and only 0.005 normal sodium sulphate. Also a majority of the roots could retain their vitality in a mixture containing equal volumes of 0.0025 normal magnesium sulphate and of 0.01 normal sodium sulphate, but not in 0.0025 normal magnesium sulphate plus 0.005 normal sodium sulphate. Similar results were obtained by adding sodium sulphate to magnesium chloride and sodium chloride to magnesium sulphate. The reverse was true, however, in the mixtures of magnesium chloride and sodium chloride, the less concentrated solution of the latter proving more beneficial.

The concentrations are stated, as in preceding tables, both in parts of salt to 100,000 of solution and in fractions of a normal solution.

In the following tables of the effects of mixtures each of the more soluble alkali salts (excepting sodium bicarbonate) is taken up in succession in the order of its toxicity in pure solution. The neutralizing effect is expressed in terms of the greatest concentration of the more toxic salt endurable in the presence of the less toxic one. As the determination of the value of a less injurious salt in neutralizing a more toxic one was the objective of all experiments with mixtures, it follows that the number of added salts decreases successively from table to table. For comparison, the limit of endurance for the more toxic salt in pure solution is stated at the head of the table. The details of neutralizing effect upon each salt are taken up in connection with its respective table, while a discussion of the general significance of the whole series of experiments with mixtures of two solutions is appended.

The results embodied in Tables III to IX were obtained from experiments with *Lupinus albus* only. In Table X, however, the limits are given for both *Lupinus albus* and *Medicago sativa* (alfalfa) in solutions of each readily soluble salt (excepting calcium chloride) in the presence of an excess of calcium sulphate and calcium carbonate together.

MAGNESIUM SULPHATE IN MIXTURES.

The following table shows the results of experiments with Lupinus in solutions of magnesium sulphate with other salts added:

TABLE III.—*Limits for magnesium sulphate in mixtures.*

Name of salt added.	Greatest endurable concentration of magnesium sulphate.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 of solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.00125	7		
Magnesium chloride	.000625	3.5	0.0025	12
Sodium carbonate	.00125	7	.0025	13
Sodium sulphate	.00375	21	.01	80
Sodium chloride	.0075	42	.015	87
Calcium chloride	.2	1,120	.2	1,101
Magnesium carbonate	.01	56	Saturated.	Saturated.
Calcium carbonate	.02	112	Saturated.	Saturated.
Calcium sulphate	.6	3,360	Saturated.	Saturated.
Calcium sulphate and calcium carbonate	.4	2,240	Saturated.	Saturated.

In the light of figures given above, the enormous discrepancy between the results obtained by experiments with this salt in pure solution and the limit determined by field survey is completely obliterated. For in alkali lands magnesium sulphate is rarely, if ever, found in any quantity except in the presence of calcium sulphate; and it is commonly accompanied by both sodium and calcium sulphate (the Billings, Mont., type of alkali soil[1]). Addition of sodium sulphate, which is itself so injurious in a pure solution, raises the limit for magnesium sulphate three times, while the presence of calcium sulphate allows a small proportion of the roots to barely survive during twenty-four hours in a solution of magnesium sulphate 480 times as concentrated as that which, in pure solution, represents the limit of endurance. A careful comparison was made between 0.3 and 0.4 normal solutions of magnesium sulphate, both in the absence and the presence of an excess of calcium sulphate, five individuals of *Lupinus albus* being cultivated for 48 hours in each of the four solutions. The following table gives the results:

TABLE IV.—*Magnesium sulphate with and without calcium sulphate.*

Solutions.	Average elongation of the marked portion of the root.	General condition of the roots.
	Millimeters.	
Magnesium sulphate (0.3 normal)	0.7	Extremely flaccid, and discolored with brownish blotches; extremely plasmolyzed.
Magnesium sulphate (0.3 normal) + calcium sulphate.	10.2	Turgor normal; plasmolysis none; but all roots quite badly discolored.
Magnesium sulphate (0.4 normal)	.3	About as in 0.3 normal.
Magnesium sulphate (0.4 normal) + calcium sulphate.	13.0	Turgor normal; plasmolysis none; all but one root quite badly discolored.

In both pure solutions the protoplasm of the nearly isodiametric cells of the periblem was completely withdrawn from the cell wall and collected with the nucleus in a compact mass near the center of the cell; while in both solutions to which calcium sulphate had been added no trace of plasmolyzing action could be detected in the cells of the periblem, the protoplasm being closely applied to the wall, with large vacuoles in the older cells, and the nucleus usually peripheral. Precautions were taken while preparing the sections to keep the tissues immersed in the culture solution, and the absence of plasmolysis in the roots taken from the solutions containing calcium sulphate is sufficient evidence that the pure solutions had produced this effect during the period of culture rather than after withdrawal.[2]

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[1] See Whitney and Means, Bul. 14, Div. Soils, U. S. Department of Agriculture (1898), and Cameron, Bul. 17, p. 32, Div. Soils, U. S. Department of Agriculture (1901).

[2] Wolf's observation (see footnote, p. 40) that both Ca $(NO_3)_2$ and Mg $(NO_3)_2$ are readily absorbed by plant roots when mixed together, while neither is readily absorbed from a pure solution, renders it highly probable that in this case of a mixture of $MgSO_4$ and $CaSO_4$ it is the rapid endosmosis of the salts into the cells of the plant roots which prevents plasmolysis of the latter. In short this mixture is to be compared with those substances described by Overton [Vierteljahrsschr. Naturf. Gessells ch. Zürich **40**, 1 (1895)] which produce only transient plasmolysis, owing to their more or less rapid passage through the ectoplasm into the cell sap. As determined by De Vries [Jahrb. für wiss. Botanik, **14**, 537 (1884)], a 1.8 per cent solution of magnesium sulphate (which would correspond to our 0.3 normal

In the presence of both calcium sulphate and calcium carbonate added in excess to a solution of magnesium sulphate, the limit of endurance is only two-thirds as high as when calcium sulphate alone is added.

Calcium as the chloride has also a powerful effect in neutralizing the toxicity of magnesium sulphate. But here the addition of a new anion (Cl), besides the added cathion (Ca), seems to diminish the beneficial effect of the latter, since the chloride, although a readily soluble salt, raised the limit for magnesium sulphate only one-third as much as does the little-soluble calcium sulphate. In a mixture of calcium chloride and magnesium sulphate a crystalline precipitate of calcium sulphate separates slowly or rapidly in proportion to the concentration of the solutions, so that the case becomes that of the contact of solid calcium sulphate with a solution of magnesium chloride. As would be expected, the limit of endurance for magnesium sulphate plus calcium chloride is the same as that for magnesium chloride plus calcium sulphate (Table V).

Sodium salts are very much less effective in neutralizing magnesium sulphate than are salts of calcium. In the case of sodium salts it is the chloride which is most effective, so that here we seem to have a beneficial effect of the anion as well as of the cathion. Yet the absence of any neutralizing effect when magnesium chloride is added to magnesium sulphate shows that the Cl ions alone are ineffective.

In one case the addition of a salt with a common basic ion—i. e., magnesium carbonate—raises the limit of endurance in magnesium sulphate eight times.[1] By a simple process of elimination, since magnesium ions are ineffective in the form of magnesium chloride when added to magnesium sulphate, although chlorine ions appear to have in themselves some neutralizing value when added as sodium chloride, we are compelled to attribute the beneficial influence of magnesium carbonate to CO_3, or more probably HCO_3, ions, a point to which we will return in discussing the stimulating effect of dilute solutions of sodium carbonate and sodium bicarbonate. Noteworthy is the fact that calcium carbonate, although much less soluble than the corresponding salt of magnesium, is twice as effective an antidote for magnesium sulphate. This affords another striking proof of the great efficacy of calcium as a remedy for magnesium poisoning.

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solution), is the isotonic equivalent of a 0.1 normal solution of potassium nitrate, which is usually taken as the unit in measurements of osmotic pressure of solutions. True [Bot. Gazette, **26**, p. 410 (1896)] found that plasmolysis of Spirogyral cells in a KNO_3 solution first appeared at a concentration of 0.25 normal. De Vries' results seem to indicate that the osmotic value of each component in a mixed solution (of two or three salts) is equal to that of the respective component when present alone at the given concentration, a point not in accord with well-established facts.

[1] The roots barely survive in poor condition in a 0.01 normal magnesium sulphate solution plus an excess of magnesium carbonate; but in 0.005 normal magnesium sulphate solution plus magnesium carbonate some of the roots were perfectly normal after a twenty-four hours' culture.

MAGNESIUM CHLORIDE IN MIXTURES.

The results of experiments with magnesium chloride in mixtures with other salts are shown in the following table:

TABLE V.—*Limits for magnesium chloride in mixtures.*

Name of salt added.	Greatest endurable concentration of magnesium chloride.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 of solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.0025	12		
Sodium carbonate	.0025	12	0.00375	19.5
Sodium sulphate	.01	48	.01	80
Sodium chloride	.01	48	.02	116
Calcium chloride	.1	480	.15	728
Magnesium carbonate	.0025	12	Saturated.	Saturated.
Calcium carbonate	.04	192	Saturated.	Saturated.
Calcium sulphate	.2	960	Saturated.	Saturated.
Calcium sulphate and calcium carbonate	.2	960	Saturated.	Saturated.

In the alkali soils of the Western United States magnesium chloride rarely occurs in such large quantities as to be regarded as more than secondary in importance.[1]

As in the case of magnesium sulphate, calcium is found to be much more effective than sodium in neutralizing magnesium, but here calcium chloride is relatively more effective than with magnesium sulphate, raising the limit for magnesium chloride one-half (instead of only one-third) as far as does calcium sulphate. But calcium is much less effective with the chloride than with the sulphate of magnesium, as is evident from the relative efficacy of calcium sulphate in raising the limits of endurance of the two magnesium salts. Hence we have here another indication (as in the case of calcium chloride added to magnesium sulphate) that chlorine ions by their presence lower the neutralizing efficacy of calcium; although in the absence of the latter base, magnesium chloride is only one-half as toxic as is magnesium sulphate. While the beneficial effect of calcium sulphate upon magnesium sulphate is decreased by the addition of an excess of calcium carbonate, the presence of the carbonate does not affect the value of calcium sulphate as an antidote to magnesium chloride.

While calcium carbonate is equally effective in raising the limits of the two soluble magnesium salts (sixteen times), magnesium carbonate, which raised the limit of magnesium sulphate eight times, has no effect upon magnesium chloride. As it appears to be necessary to regard the HCO_3 ions as the effective element in the former combination, we must conclude that these act beneficially in the presence of Mg and SO_4, but are powerless in the presence of Mg and Cl. But as calcium carbonate is equally effective as an antidote to magnesium chloride and to magnesium sulphate, it would follow that the power of Cl ions to hinder the effect of HCO_3 ions disappears in the presence of Ca ions, while, as already noted, Cl ions appear to diminish the value of Ca ions as an agency for counteracting Mg ions. Comparisons such as these show how difficult it is to attempt an interpretation of toxicological phenomena in the light of current chemical and physiological ideas. Possibly determinations of the solubility and degree of dissociation of these different salts in mixtures may afford some clue to the numerous anomalies. On the other hand, it is difficult to see any justification for using the reactions of organisms in determining the dissociation constants of electrolytes. The many nonconcordant results recently described in the literature can hardly be regarded as throwing discredit upon the dissociation hypothesis, but rather as demonstrating the unsatisfactory nature of the method employed for the investigation in hand.

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[1] Magnesium rarely makes its specific effects upon plant life felt in the "alkali" soils, owing to the omnipresence there of considerable calcium salts. In certain areas of the Eastern States, notably in the so-called "serpentine barrens" of Pennsylvania and Maryland, it appears to be relatively more important, probably because it is there present in excess over calcium, although the actual amount of both, which may be present in the soil solutions at any given time, must be extremely small.

Sodium sulphate and sodium chloride are equally effective in raising the limit of magnesium chloride (four times). The former is more effective, and the latter decidedly less so, than in the case of magnesium sulphate, so that the anions (Cl, SO_4) and not alone the cathions (Mg, Na) appear to make their influence felt in these cases.

SODIUM CARBONATE IN MIXTURES.

Table VI shows results of experiments with mixtures of other salts with sodium carbonate:

TABLE VI.—*Limits for sodium carbonate in mixtures.*

Name of salt added.	Greatest endurable concentration of sodium carbonate.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.005	26		
Sodium sulphate	.0075	39	0.01	80
Sodium chloride	.0025	13	.01	58
Calcium chloride	.25	1,300	.25	1,377
Magnesium carbonate	.01	52	Saturated.	Saturated.
Calcium carbonate	.0075	39	Saturated.	Saturated.
Calcium sulphate	.03	156	Saturated.	Saturated.
Calcium sulphate and calcium carbonate	.03	156	Saturated.	Saturated.

As the above table shows, sodium chloride is ineffective as an antidote to sodium carbonate; calcium carbonate barely raises the limit of endurance, while magnesium carbonate merely doubles it. It is interesting that magnesium carbonate should here be more effective than the corresponding salt of calcium, since in all other cases the latter is the more beneficial.[1] Sodium sulphate is likewise of very little neutralizing value, and the soluble salts of magnesium possess none so far as was ascertained. Calcium sulphate raises the limit only six times, the presence or absence of an excess of calcium carbonate not affecting the value of the sulphate. This comparatively slight efficacy of calcium sulphate in neutralizing "black alkali" is rather surprising in view of the accepted ideas of students of alkali soils in regard to the curative value of gypsum.[2] The comparative inefficacy of calcium sulphate in this case contrasts strikingly with its power to neutralize sodium in the forms of sulphate (Table VII) and chloride (Table VIII).

Calcium chloride is the only salt found to be very effective in neutralizing sodium carbonate, raising the limit of endurance for the latter fifty times. A mixture of solutions of the two salts causes an immediate heavy precipitate of calcium carbonate, to which fact the efficacy of the added salt must be largely ascribed. We should be dealing in this case with a solution of sodium chloride containing a large excess of calcium carbonate. Yet by direct addition of solid calcium carbonate to a solution of sodium chloride, the limit of endurance for the latter can be raised only three times, i. e., to 0.06 normal (see Table VIII). Here again chemistry appears to be powerless to afford an explanation of a phenomenon which, in the present state of our knowledge, must be regarded as paradoxical.[3]

A very noteworthy result was obtained by experiments with sodium carbonate, as well as with sodium bicarbonate, in the presence of an excess of calcium sulphate and calcium carbonate. In solutions of critical concentration of both of these mixtures a majority of the roots of the lupine plants were completely destroyed with pronounced corrosion due presumably to the action of hydroxyl ions, while a smaller number survived in apparently perfect condition, and this occurred in repeated experiments. In critical solutions of other salts and mixtures of salts, however, there was rarely such sharp difference in appearance between roots which survived and those which died during twenty-four hours' culture; as a rule none of the roots were in normal condition at the end of the experiment. In other words, the difference of individual plants in their power to resist toxic action appears to be more pronounced in the case of the two carbonates of sodium than of other "alkali salts." This would indicate that the selection of plants for resistance to "black alkali" offers a simpler problem than where resistance to other components of alkali soils is to be sought.

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[1] The probability of the formation of a double carbonate, with a consequent lowering of the active mass, as well as a probable change of nature of the ions, suggests itself very forcibly in this connection. It is hoped that time and opportunity will be found in the near future to test this supposition in the laboratory.

[2] Hilgard. Bul. 128, Agr. Exp. Sta., Univ. Calif., pp. 16 to 18 (1900). It should be stated, however, that Hilgard recommends the application of gypsum under physical conditions which would not probably be considered analogous to those under which the experiments here described were performed.

[3] In marked contrast with this anomalous case is that of the mixture of magnesium sulphate and calcium chloride, in which a precipitate of calcium sulphate is formed and which is therefore to be regarded as a solution of magnesium chloride containing a solid excess of calcium sulphate. Here the limit of endurance is the same as when solid calcium sulphate is added directly to a solution of magnesium chloride. The same thing is true of a mixture of sodium sulphate and calcium chloride in which the limit of endurance is the same as for sodium chloride plus calcium sulphate.

SODIUM SULPHATE IN MIXTURES.

Experiments with sodium sulphate in mixtures with other salts show the following results:

TABLE VII.—*Limits for sodium sulphate in mixtures.*

Name of salt added.	Greatest endurable concentration of sodium sulphate.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 of solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.0075	53	....	....
Sodium chloride	.00375	26.5	0.01	58
Calcium chloride	.2	1,272	.2	1,102
Magnesium carbonate	.03	212	Saturated.	Saturated.
Calcium carbonate	.04	281	Saturated.	Saturated.
Calcium sulphate	.5	3,530	Saturated.	Saturated.
Calcium sulphate and calcium carbonate [a]	.3	1,906	Saturated.	Saturated.

[a] See Bul. 17., p. 22 et seq., Division of Soils, U. S. Department of Agriculture, 1901.

Sodium sulphate is very abundant in "alkali" soils, often occurring in contact with each or several of the other salts. In the Billings, Mont., type, for example, it is accompanied by the sulphates of magnesium and calcium, while in the Fresno, Cal., type it is in contact with sodium carbonate.

Most effective for neutralizing this salt is calcium sulphate, which raises the limit more than sixty times when added alone. In the presence of an excess of calcium carbonate, however, calcium sulphate can increase the limit of endurance for sodium sulphate only about forty times. This is probably due to a forcing back of the dissociation and decrease of solubility of the calcium sulphate by the calcium carbonate, although, as Cameron and Seidell[1] have shown, either salt is rather soluble in dilute solutions of sodium sulphate.

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[1] Solution Studies of Salts Occurring in Alkali Soils, Bul. 18, Division of Soils, U. S. Department of Agriculture.

As in the case of all the other salts except sodium carbonate, calcium chloride is less effective than calcium sulphate, raising the limit only twenty-seven times. In this case, as in the mixture of calcium chloride with magnesium sulphate, a crystalline precipitate of calcium sulphate is formed, so that it actually becomes a case of the contact of calcium sulphate with a solution of sodium chloride, and the same limit was obtained by a direct test of this latter mixture. Calcium carbonate is much less effective in neutralizing sodium sulphate than in counteracting the toxic action of magnesium salts.

Calcium sulphate is more effective as an antidote to sodium sulphate than to any other salt tried except magnesium sulphate. In both these cases the anion of the added salt is the same as that of the more toxic one; hence the cathions alone seem to operate. Possibly a double salt of sodium and calcium is formed in this mixture. Since calcium sulphate is much less efficacious in neutralizing the chlorides of magnesium and sodium than the corresponding sulphates, while it is generally more beneficial than is calcium chloride, it seems almost certain that the beneficial action of Ca ions is in some way hindered by the presence of Cl ions. That Cl ions are in themselves less toxic than are SO_4 ions would appear from the fact that the chlorides of magnesium and of sodium are less injurious in pure solution than are the corresponding sulphates.

SODIUM CHLORIDE IN MIXTURES.

Experiments with sodium chloride in mixtures with other salts yielded the results shown in the following table:

TABLE VIII.—*Limits for sodium chloride in mixtures.*

Name of salt added.	Greatest endurable concentration of sodium chloride.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 of solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.02	116		
Calcium chloride	.2	1,160	0.2	1,101
Magnesium carbonate	.04	232	Saturated.	Saturated.
Calcium carbonate	.06	348	Saturated.	Saturated.
Calcium sulphate	.2	1,160	Saturated.	Saturated.
Calcium sulphate and calcium carbonate	.2	1,160	Saturated.	Saturated.

Sodium chloride is probably the most widely distributed and generally abundant of the soluble components of alkali soils, occurring practically wherever the land is notably impregnated with these noxious salts.[1] As the above table shows, calcium sulphate and calcium chloride are equally effective in neutralizing the toxicity of sodium chloride, although in the case of sodium sulphate and the soluble salts of magnesium, the former is decidedly more beneficial than the latter.

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[1] A notable exception is the Billings area in Montana.

As in the case of magnesium chloride, the presence of calcium carbonate does not affect the neutralizing value of calcium sulphate, although decidedly diminishing it in the case of magnesium sulphate and sodium sulphate. It has been shown by Cameron and Seidell[1] that an excess of solid calcium carbonate has but a very slight effect on the solubility of calcium sulphate in sodium chloride solutions at the concentrations here involved. And from the general resemblance between the phenomena presented by calcium sulphate in contact with sodium chloride and magnesium chloride solutions, it is probable that calcium carbonate would have a like effect in the latter cases. It is to be regretted that laboratory investigations of the solubility of solid calcium carbonate and calcium sulphate in contact with solutions of soluble sulphates have not yet been made.

CALCIUM CHLORIDE IN MIXTURES.

In the experiments with calcium chloride in mixtures with other salts the following results were obtained:

TABLE IX.—*Limits for calcium chloride in mixtures.*

Name of salt added.	Greatest endurable concentration of calcium chloride.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 of solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.25	1,377		
Magnesium carbonate	.25	1,377	Saturated.	Saturated.
Calcium carbonate	.25	1,377	Saturated.	Saturated.
Calcium sulphate	[a]0.3	1,652	Saturated.	Saturated.

[a] About.

Calcium chloride is quite generally distributed in alkali soils, being usually present in small patches wherever sodium chloride is abundant. As would be expected from the relatively very high concentration of the pure solution of this salt endured by roots of the white lupine, the limit can not be materially raised by the addition of other salts.

SODIUM BICARBONATE IN MIXTURES.

Sodium bicarbonate was tested in mixture only with calcium sulphate and calcium carbonate together, which raised its limit of endurance two and one-half times (see Table X). It usually occurs in nature in contact with the normal sodium carbonate.

CALCIUM SULPHATE AND CALCIUM CARBONATE IN MIXTURES.

In the tables of limits of endurance in mixtures, as in those of pure solutions, the figures do not perfectly state the case. For example, although the limit of endurance in sodium carbonate plus magnesium carbonate is 0.01 normal, while for sodium sulphate plus magnesium carbonate it is 0.03 normal, the proportion of individual seedlings whose roots survive in good condition is decidedly greater in the latter mixture than in the former.

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[1] Bul. 18, Division of Soils, U. S. Department of Agriculture (1901).

None of the readily soluble salts occurs abundantly in alkali soils save in the presence of calcium sulphate or calcium carbonate, and most often in contact with both. Hence it follows that the limits of endurance for the more soluble salts in the presence of these two salts of calcium, as obtained by means of water-culture experiments, should agree closely with the limits determined by soil investigators. This proved to be the case, due allowance being made for the influence of the physical properties of a soil as compared with an aqueous solution.

The following table serves to bring together, for ready comparison, the limit of endurance for roots of both white lupine and alfalfa in solutions of six of the easily soluble salts to which a solid excess of both calcium sulphate and calcium carbonate was added, the mixtures being brought to equilibrium before using.

TABLE X.—*Results with mixtures containing two calcium salts.*

Name of salt.	Limits for lupine (Lupinus albus).		Limits for alfalfa (Medicago sativa).[a]	
	Parts per 100,000 of solution.	Normal solution.	Parts per 100,000 of solution.	Normal solution.
Magnesium sulphate	2,240	0.4	1,960	0.25
Magnesium chloride	960	.2	960	.2
Sodium carbonate	156	.03	104	.02
Sodium sulphate	2,160	.3	2,160	.3
Sodium chloride	1,160	.2	1,160	.2
Sodium bicarbonate	417	.05	667	.08

[a] In the case of alfalfa a few roots barely survive in 0.35 and in 0.3 normal magnesium sulphate, while in 0.25 normal they make a noteworthy amount of growth during forty-eight hours. In 0.2 normal sodium sulphate they make a decidedly better growth, and in 0.1 normal sodium chloride two and one-half times as much growth as in the water control.

The close correspondence between the white lupine and alfalfa in their resistance to the effects of these mixed solutions is worthy of note, especially as alfalfa appears to be more sensitive than the lupine to pure solutions. The only serious discrepancy occurs in the mixture of sodium bicarbonate, calcium sulphate, and calcium carbonate, to which alfalfa roots appear to be nearly twice as resistant as are those of white lupine.

That in the neutralizing effect upon more toxic salts which these two relatively insoluble salts exert calcium sulphate plays a much more important part than does calcium carbonate is obvious from a comparison of the limits of endurance in solutions to which either calcium sulphate or calcium carbonate alone has been added. Indeed, in the case of magnesium sulphate and of sodium sulphate the limit of endurance is decidedly lower in the presence of both calcium salts than when calcium sulphate alone is added. On the other hand, the presence or absence of calcium carbonate appears to have no effect upon the neutralizing value of calcium sulphate when added to magnesium chloride, sodium chloride, or sodium carbonate.

An interesting comparison is that of the soluble salts, one with another, in respect to their degree of toxicity in pure solution on the one hand, and in the presence of an excess of calcium sulphate and calcium carbonate on the other. It will be observed that the sequence in the first column is very different from that in the second. The most toxic salt or mixture is placed at the head of each column.

TABLE XI.—*Order of toxicity with and without calcium salts.*

In pure solution:	In presence of an excess of $CaSO_4$ and $CaCO_3$: [a]
Magnesium sulphate.	Sodium carbonate.
Magnesium chloride.	Sodium bicarbonate.
Sodium carbonate.	Magnesium chloride. [b]
Sodium sulphate.	Sodium chloride [b]
Sodium chloride.	Calcium chloride.
Sodium bicarbonate.	Sodium sulphate.
Calcium chloride.	Magnesium sulphate.

[a] It has already been suggested that the limit in some of these highly concentrated solutions containing an excess of calcium salts may bear some relation to the osmotic pressure of the solution. It is therefore not a mere coincidence, perhaps, that the sequence in this column is almost identical with that in Table II (of concentrations precluding any growth during the culture).

[b] These two salts are equally toxic in mixtures if reacting weights be compared, while magnesium chloride is the more toxic of the two in parts of salt per 100,000 of solution.

The interest and importance of the results obtained from the experiments made with mixed solutions show the great desirability of extending further this line of investigation. In fact, no aspect of the work promises more substantial returns. An interesting problem among the many which suggest themselves in this connection is that of a possible relation between the degree of toxicity of a salt, alone or in mixture, and the readiness with which it is taken up by the plant from a solution. The occasion seems opportune to redirect attention to a series of experiments made long ago by Wilhelm Wolf[1] as to the

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[1] Landw. Versuchsst., 7, 193 (1865). The studies were made with a series of solutions, each of which contained two salts in equal amount. Combinations were made with (1) salts of the same acid, but of different bases; (2) salts of the same base, but of different acids; (3) with both base and acid different. In each culture 200 c. c. of solution was employed, and after one-half of this volume had been absorbed by the plant (allowance being made for the small quantity of water evaporated directly from the solution) the amount of each salt taken up with the water was estimated by analysis of the residual 100 c. c. of solution. Young beans and maize were used in the experiments. Some of the results obtained were as follows:

From three mixtures, each containing 0.05 grams of each two salts, the plants absorbed in percentages of the original quantity of each salt supplied:

From ammonium nitrate plus calcium nitrate, 92 per cent of the former and 94 per cent of the latter.

From ammonium nitrate plus magnesium nitrate, 92 per cent of the former and 86 per cent of the latter.

From magnesium nitrate plus calcium nitrate, 74 per cent of each.

Potassium nitrate was taken up from all combinations with other nitrates amount of each salt absorbed by a plant from a mixed solution. Especially interesting, as compared with the toxicological phenomena of pure and mixed solutions, respectively, are Wolf's results as to the effect of calcium sulphate in stimulating the absorption of other sulphates.

GENERAL SIGNIFICANCE OF RESULTS WITH MIXED SOLUTIONS.

To enter into a discussion, from the purely chemical point of view, of the widely accepted hypothesis of the dissociation of electrolytes in solution would be to exceed the proper limits of this paper.[1] It is sufficient to say that salts such as those with which we are here dealing are held to dissociate in dilute solutions, more or less com-

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(Na, NH_4, Mg, Ca) in absolutely greater amount than from a simple solution. From a solution containing 0.025 gram each of potassium nitrate and calcium nitrate the plants absorbed 100 per cent of the former and 88 per cent of the latter. From an equivalent solution of potassium nitrate plus magnesium nitrate, 100 per cent of the former and 88 per cent of the latter. The stimulation of the plant by the presence of calcium to take up greater quantities of potash is referred by Loew (l. c., p. 44) to the increased development of root hairs induced by the calcium. But if the presence of magnesium has exactly the same effect, as would appear from the experiment just quoted, we must look further for an explanation. Absorption of ammonium nitrate is decreased by the presence of other nitrates, *while that of calcium and of magnesium nitrates is stimulated thereby. It is remarkable that while neither of these last two salts is readily absorbed from a simple solution, both are easily absorbed when mixed together.*

Plants could be grown in mixtures of potassium and calcium sulphate ($K_2SO_4 + CaSO_4$) and of calcium and magnesium sulphate ($CaSO_4 + MgSO_4$), but never in mixtures of sulphates of potassium and sodium ($K_2SO_4 + Na_2SO_4$), of potassium and ammonium ($K_2SO_4 + (NH_4)_2SO_4$), nor of potassium and magnesium $K_2SO_4 + MgSO_4$), even when the solutions were very dilute.

Potassium and ammonium salts were taken up much more readily in the presence of a calcium salt than from a pure solution. This was notably the case with the sulphates, which are absorbed with difficulty from unmixed solutions. Gypsum (calcium sulphate) is absorbed in very small quantity in the presence of a potassium salt, but greatly stimulates absorption of the latter. From a mixture of calcium and magnesium sulphate little of either salt is taken up, but the presence of magnesium nitrate considerably increases the amount of calcium sulphate drawn from a solution.

From mixtures of a sulphate and a phosphate, the latter is always taken up in greater quantity. Magnesium sulphate is taken up in greater quantity in the presence of a phosphate than are other sulphates.

De Saussure's principle of the absorption of salts in solution by plant roots—i. e., that the salt is taken up in smaller proportion to the water absorbed than it occurs in the culture solution; in other words, that the residual solution becomes more concentrated—applies to the absorption of sodium chloride in the presence of a nitrate (KNO_3, NH_4NO_3, $Ca(NO_3)_2$), but does not hold as to the absorption of the nitrate itself.

[1] For the presentation of the subject in simple terms the reader is referred to a former publication by one of us. (Rep. No. 64, U. S. Department of Agriculture, p. 144, 1900.)

pletely at a given concentration according to the specific properties of the particular salt. The result is a liberation of ions—atoms or atomic groups carrying or in some way associated with an electric charge. Cathions, those furnished by the basic radicle, carry positive electricity, while anions, derived from the acid radicle of the salt, are negatively charged. Ions possess a much greater velocity[1] than do undissociated molecules, and it is now believed by many physiologists that salts owe to the properties of their ions rather than to their entire molecules the toxic and other action which they exert upon organisms.[2]

It is believed that the results of the present investigation tend to confirm this view, although it must be admitted that serious anomalies exist, to some of which attention has already been directed.

Pure solutions of the salts dealt with are shown to be generally injurious to plants, and this largely by virtue of the cathions which they yield, as a comparison of the position of the several salts in the table of toxicity in pure solutions shows conclusively. Thus magnesium salts, irrespective of the character of their anions, are much more injurious than is any sodium salt, while the three chlorides (of magnesium, sodium, and calcium) differ enormously in toxicity, regardless of the fact that they yield a common anion.

An inspection of the tables of limits in mixed solution given above makes it clear that the addition of a second, less toxic salt in most cases increases the concentration of solution of the more harmful one in which root tips can retain their vitality. It is also demonstrated that addition of a second salt of the same base, hence furnishing a different kind of anion only, is usually much less efficacious in raising the limit than is the admixture of a salt of a different base. Thus magnesium chloride is ineffective as an antidote to magnesium sulphate, sodium chloride to sodium carbonate or to sodium sulphate, and calcium carbonate to calcium chloride.

If the assumption be granted that in the dilutions here involved the magnesium salts are practically completely dissociated and that the anions do not have a toxic effect, then a 0.00125 normal solution of magnesium will be the limit when the metal is combined as the sulphate and a 0.0025 normal solution when combined as the chloride, but about a 0.002 normal solution when both chloride and sulphate are present, with two equivalents of the former to one of the latter. The same line of reasoning holds for the other cases cited, and from these facts it is evident that the anions have a part in determining the toxic effect of a salt, although a much smaller one in general than have the cathions. Furthermore, these views are in harmony with Loeb's idea that SO_4 ions are more toxic than Cl ions, because they tend to precipitate calcium from its proteid compounds.

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[1] That the physiological action of ions may be in some sort a function of their specific velocities is indicated by Loeb's comparison of the effects of hydrogen and hydroxyl ions, as well as of various basic cathions, upon the absorption of water by a muscle. [Pflüger's Archiv., 69, 21, (1898).]

[2] Of a rapidly growing literature on this subject the papers of Kahlenberg and True and of Kahlenberg and Austin, dealing with plants, and those of Loeb, Garrey, Anne Moore, Kahlenberg, Clark and others, treating ion action upon animals, may be cited as of great importance. (See the Bibliography, p. 56.)

In other cases, however, addition of a salt which furnishes new anions, but not new cathions, to the mixture is effective in raising the endurable limit of concentration for the more toxic salt. A striking case is the elevation of the limit for magnesium sulphate eight times by the addition of magnesium carbonate. Here it would appear that the HCO_3 anions alone can be the effective agency. Sodium sulphate slightly raises the limit of sodium carbonate, and a relatively unimportant increase of the concentration of a calcium chloride solution in which lupine roots can survive is obtained by addition of calcium sulphate. But in these last two cases the effect is so small as to be almost negligible, and is perhaps entirely attributable to the forcing back of the dissociation of the more toxic salt rather than to any direct physiological action of the new anions.

The superior efficacy of cathions over anions in neutralizing the toxic effect of other cathions is illustrated by the discovery that sodium is equally effective as an antidote to magnesium chloride, whether it be added as sulphate (Na_2SO_4) or as chloride (NaCl).[1] A much more striking illustration is afforded by the fact that calcium, when added to a solution of magnesium sulphate or of sodium sulphate, is very much more efficacious when furnished as the relatively insoluble sulphate than as the readily soluble chloride. In other words, the presence of chlorine anions actually hinders the full exertion of the physiological effect of calcium cathions, unless we are to believe that the superior efficacy of calcium sulphate is due merely to its greater influence in retarding the dissociation of the sulphates of magnesium and of sodium.

If we turn now to the effect of mixtures in which two kinds of cathions are present we find that these are almost invariably much less poisonous than is the pure solution of the more toxic salt. Even the addition of a sodium salt (sulphate or chloride) to one of magnesium (sulphate or chloride) raises the limit of endurance for the latter three to six times. Still more remarkable is the effect of magnesium carbonate as an antidote to salts of sodium (carbonate, sulphate, chloride), raising their limits two to four times. But these effects are trivial as compared with the extraordinary efficacy of calcium in counteracting the toxic effects of other bases (magnesium, sodium).

Even when added as the but slightly soluble carbonate, calcium raises the limit of magnesium sulphate and of magnesium chloride sixteen times, of sodium sulphate more than five times, and of sodium chloride three times. Calcium chloride[1] mixed with an equal volume of a magnesium or a sodium salt raises the limit of the latter as follows: Magnesium sulphate, one hundred and sixty times; magnesium chloride, forty times; sodium carbonate, fifty times;[2] sodium sulphate, twenty-seven times, and sodium chloride, ten times.

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[1] On the other hand, sodium chloride is twice as effective as sodium sulphate in neutralizing magnesium sulphate.

The most effective of the calcium salts tried was, however, calcium sulphate. This, when added alone in solid excess, increases the maxima of concentration endurable by the roots as follows: Magnesium sulphate, four hundred and eighty times; magnesium chloride, eighty times; sodium carbonate, six times; sodium sulphate, sixty-six times, and sodium chloride, ten times. Here we have probably the greatest effect of one kind of ion in neutralizing the effect of another kind that has yet been obtained in experiments with plants.

It is noteworthy that the effect of the calcium ions upon different salts having a common basic ion differs greatly. Thus plant roots can endure three times the concentration of a solution containing magnesium cathions and sulph-anions to which calcium sulphate is added than they can of a solution containing magnesium cathions and chlor-anions plus calcium sulphate. Yet the former solution in the absence of calcium salts is endurable in concentration only one-half as great as is the latter without a calcium salt. Here the effect may be partly due to differences of dissociation in the two solutions. But it appears necessary to attribute the greater part of it to an adverse influence, presumably exerted by chlorine ions, upon the physiological action of calcium ions in the presence of magnesium ions. Similar problems are suggested by the wide differences in the degree to which calcium sulphate can neutralize the toxic action of each of the three sodium salts.

That the phenomena exhibited by the roots of plants in their reaction to these various mixed salt solutions are not to be regarded as mere functions of chemical changes in the solution itself is patent. The problem is undoubtedly a much more intricate one, involving chemical reactions of great complexity in the protoplasm of the plant itself. In this connection it is important to call attention to the strikingly similar results obtained by Loeb[3] as to the relative toxic effect upon animals of pure and of mixed solutions.

A pure salt solution, e. g., of sodium chloride, was found to be strongly poisonous to marine animals in various stages of development—i. e., a fish (*Fundulus heteroclitus*), a jellyfish (Gonionemus sp.), and a sea urchin (Arbacia sp.). But the addition in small quantity of a salt yielding another kind of cathion, such as magnesium, potassium, and calcium, more or less neutralized this toxic effect, although each of these salts was itself toxic in pure solution. As in the case of plants, calcium was particularly effective. That it is the cathions rather than the anions added to the solution which are chiefly effective as counter agents is evident from the fact that of each base the chloride only was used. Moreover, in only one mixture of three chlorides could fertilized eggs of the sea urchin be brought to an advanced stage of development, but sodium bromide could be successfully substituted for sodium chloride in the mixture.[1] It is clear, therefore, that the anions play a very subordinate part in the physiological action of such mixtures.

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[1] Loew (Bul. No. 18, Div. Veg. Phys. and Path., U. S. Department of Agriculture, p. 33), referring to an experiment made by Boehm, appears to doubt the value of calcium in the form of the chloride as a plant nutrient, owing to the formation of hydrochloric acid in the assimilation of calcium by the plant. Here is another suggestion as to the reason for the inferiority of calcium chloride to calcium sulphate in neutralizing the toxic action of salts of other bases.

[2] As has already been noted (under Table VI), a heavy precipitate of calcium carbonate is formed in this mixture, so that it becomes in great part a solution of sodium chloride plus a solid excess of calcium carbonate.

[3] See the papers by this author cited in the Bibliography (p. 58).

Loeb suggests that the physiological effect of a pure solution, whether toxic or stimulating, is attributable to a reaction whereby various cathions which are assumed to enter into combination with the proteids of the organism are replaced by the cathion of the surrounding solution, in accordance with the law of mass. Thus, in case of an animal or organ immersed in a solution of sodium chloride, ions of calcium and of potassium would be forced from their organic compounds and sodium ions would be substituted for them. This would cause a disturbance of equilibrium and finally a cessation of irritability in the tissues. Such effect can be prevented, or, if it has not proceeded to the point of disorganization, counteracted by the addition to the solution of salts containing the corresponding cathions, i. e., potassium and calcium. Hence the author derives his conception of a "physiologically balanced salt solution," examples of which are sea water, the blood of animals, and a mixture of definite concentrations of the chlorides of potassium, sodium, and calcium. The chief function of such a solution is regarded as the maintenance of "a certain physical condition, a certain labile equilibrium, of the protoplasm or the colloids."[2]

From considerations such as these, and from the discovery that a close analogy as to absorption of water exists between the behavior of a frog's gastrocnemius immersed in a solution of a potassium, sodium, or calcium salt and that of potassium, sodium, and calcium soaps,[3] the development of Loeb's theory of the existence and function of "ion-proteid compounds" was logically inevitable. The hypothesis is stated as follows: "Salts or electrolytes in general do not exist in living tissues as such exclusively, but are partly in combination with proteids. The salt or electrolyte molecules do not enter into this combination as a whole, but through their ions. The great importance of these ion-proteid compounds lies in the fact that by the substitution of one ion for another the physical properties of the proteid compounds change. We thus possess in these ion-proteid compounds essential constituents of living matter which can be modified at desire, and hence enable us to vary and control the life phenomena themselves. * * * If it be true that life phenomena depend upon the presence of a number of various metal proteids (Na, Ca, K, and Mg) in definite proportions, it follows that *solutions which contain only one class of metal ions must act as a poison.* The reason for this is that the one class of metal ions will gradually take the place of the other metal ions in the ion-proteids of the tissues. Even a pure NaCl solution must thus be poisonous, although this salt permeates all our tissues and is the main constituent of the [soluble] inorganic matter of the ocean."[1]

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[1] Amer. Journ. Physiology, 3, 442 (1900).

[2] Ibid., 3, 445 (1900).

[3] See Pflüger's Archiv, 75, 303 (1899).

Pauli,[2] who published the same hypothesis almost simultaneously, states his views with greater positiveness. "The general distribution of the ion-proteid compound in the living organism can not be doubted; indeed, we have strong reasons for the assumption that all the proteids of the protoplasm exist there only in combination with ions." And again, "Not salts, but salt-ions, are indispensable to the organism."[3]

Loeb's experiments show that to the same ions or mixtures of ions different animals or different organs or stages of development of the same animal may react in a different manner. This was noted in the case of embryonic as compared with fully developed tissue and with myogenic as compared with nuerogenic contractions. Thus in pure solution magnesium chloride is more favorable to the development of fertilized eggs of the sea urchin than is sodium chloride, although the latter causes while the former prevents rhythmical muscular contraction. On the other hand, as the predominant salt in a triple mixture of chlorides (potassium and calcium being present in much smaller quantity), sodium chloride favors, while magnesium chloride prevents, the development of fertilized sea-urchin eggs.[4] Calcium ions prevent rhythmical muscular contraction, but allow the muscle to retain its irritability much longer than is possible in a solution from which they are absent.[1] Results similar to those obtained by Loeb have recently been recorded by other investigators.[2]

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[1] Amer. Journ. Physiology, 3, 327 (1900).

[2] Ueber physikalisch-chemische Methode und Probleme in der Medizin, 19, Wien (1900).

[3] Loew, although attempting no such extensive generalization, has touched upon the question of ion proteids and their relation to vital phenomena in his discussion of the harmfulness to plants exhibited by magnesium salts in the absence of calcium. (See Bul. No. 18, Div. Veg. Phys. and Path., U. S. Department of Agriculture, p. 42, 1899.)

[4] Amer. Journ. Physiology, 3, 439 (1900).

That the converse case may also occur is indicated by Loeb's investigations: "Different combinations of ions may exist which all have the same effect. It seems as if the physical condition of the colloids were the essential point and that this might be affected by various ion combinations in the same way."[3]

It is not to be doubted that many peculiarities in relation to ions will likewise be discovered in plants as compared with animals. A case in point is that of magnesium chloride, which in pure solution is eight times as toxic as sodium chloride to roots of the white lupine and of alfalfa while the two salts are about equally toxic when calcium is present. Hence lupine roots react toward these two salts in a wholly different manner than do sea-urchin eggs. Furthermore, a comparison of different plants, one with another, or of different organs or stages of development in the same plant, will surely reveal numerous dissimilarities.

The importance of the ion-proteid theory as an aid to the study of the effects, both toxic and beneficial, which solutions of electrolytes induce in organisms, can hardly be overestimated. It is to be regarded as the only really scientific explanation of this class of phenomena which has yet been attempted. Incomplete as the theory is in its present form, and many as are the anomalies needing further study, we can not but welcome it as a most promising instrument wherewith to attack the vast problem of the physical properties and energies of protoplasm.[4]

Meanwhile it is highly desirable that the study of ion action upon plants be extended. Experiments should be made with a larger number of different ions, and with mixtures containing more than two kinds of cathions.[5] It is most essential that many species of plants be tested in order that we may determine what classes of reaction to ions are peculiar to certain groups of organisms and what, if any, may be regarded as generic properties of protoplasm. No less important, as Loeb's work with animals has conclusively shown, will be the comparative study of different organs and functions and stages of growth in the same plant, as to their different reactions to the same ions and combinations of ions.

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[1] Festschrift für Adolf Fick, p. 111 (1899).

[2] See the papers of Garrey, Anne Moore, Cushing, Lillie, and Stiles cited in the Bibliography, (p. 56). True has lately experimented with *Cladophora gracilis* grown in various synthetic solutions resembling sea water, and has made the highly interesting discovery that an indefinite prolongation of life could be obtained only when a solution equivalent to sea water in its other components, but containing much more NaCl, was employed. Addition of calcium and potassium salts was found necessary in order to neutralize effectively the toxic action of a sodium salt solution.

[3] Amer. Journ. Physiology, 3, 443 (1900).

[4] For certain limitations of the theory as now formulated reference should be made to the very important paper of Kahlenberg [Journ. Physical Chem., 5, 339 (1901)].

[5] Loeb's discovery that fertilized eggs of the sea urchin could be developed to the pluteus stage in mixtures of three, but not of two chlorides, indicates that much is to be expected from such an extension of these investigations. See Amer. Journ. Physiology, 3, 441, (1900).

From the point of view of agriculture the ion-proteid theory will doubtless throw light upon much that is now obscure and even paradoxical in the relation between the plant and the soluble components of the soil. Nothing is more certain, in the light of such observations as are recorded in this paper, than the inadequacy of soil physics and soil chemistry alone to explain many details of this relation. The chemistry of protoplasm and its proteid compounds must surely be taken into account before we may hope to get to the bottom of the subject.

STIMULATING EFFECT OF DILUTE SOLUTIONS.

As an incident of these investigations it was demonstrated that in the case of certain salts, when plant roots are exposed to pure solutions which are much too dilute to produce any toxic effect, there occurred a decidedly stimulating effect upon growth, as compared with that in the distilled-water control during a corresponding period. As would be expected, this was shown to be the case for salts of calcium, both the chloride and the sulphate acting as stimuli. Here, however, we have to do with salts which contain valuable elements of plant food.

But a marked stimulating action occurs in pure solutions of sodium carbonate (slight in 0.002 normal, marked in 0.00125 normal and of sodium bicarbonate 0.01 normal). The most pronounced effect was obtained in a 0.00125 normal solution of sodium carbonate, the average elongation of the roots in that solution being one and one-half times as great as in distilled water during the same period. In the case of the two carbonates of sodium it seems necessary to regard the effect as one of chemical stimulus, pure and simple. That this is not due to the sodium ions is evident from the fact that very dilute solutions of other sodium salts (sulphate, chloride) gave purely negative results. It was at first thought that the physiological effects of sodium carbonate (Na_2CO_3) were attributable to the presence of hydroxyl ions in the solution, since the corrosive, clearing action of more concentrated solutions of this salt is precisely similar to that produced by potassium hydrate and sodium hydrate. But toxic, as well as stimulating reactions of exactly the same character were obtained with solutions of the bicarbonate ($NaHCO_3$), in which a large excess of carbon dioxide was dissolved, and which gave no reaction with phenolphthaleine, even at the end of the experiment.[1] In this case the consideration of free hydroxyl ions must be excluded. Hence the conclusion seems unavoidable that the carbonic acid (HCO_3) ions produce the stimulating effect, improbable as this would appear. To what agency should be ascribed the characteristic toxic action (so different in kind from that of sodium sulphate and sodium chloride) of stronger solutions of sodium bicarbonate, in which no free hydroxyl could be detected, is a question to which no answer can at present be given.[1]

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[1] Solutions of sodium carbonate which were many times too dilute to produce a stimulating effect, yet gave a strong reaction with phenolphthaleine.

None of the other salts with which experiments were made in pure solution were shown to stimulate elongation of the roots, although the possibility is not excluded that solutions still more dilute than those employed will give positive results. Magnesium sulphate was found to be indifferent (neither toxic nor stimulating) at 0.0003125 normal, magnesium chloride at 0.000625 normal, sodium sulphate (nearly) at 0.002 normal, and sodium chloride[2] (approximately) at 0.005 normal.

These observations accord with the well-known principle that many violent poisons, if given in sufficiently minute doses, serve as beneficial stimuli. Familiar examples are the action of arsenic, mercury, strychnine, digitaline, etc., upon animals. Numerous investigators have obtained similar effects with plants by supplying them with very small quantities of various substances which can not be regarded as sources of plant food, such as the extremely toxic salts of some of the heavy metals. In practically all such cases, however, it is very probable that considerable hydrolysis had taken place and that the stimulation might well be attributed to the hydroxyl ions thus introduced into the solution.

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[1] In experiments with sodium carbonate and sodium bicarbonate as to their effect upon animals, Loeb encountered a very similar anomaly. The stimulating effect of various hydrates upon the absorption of water by a muscle immersed in a sodium chloride solution was shown to be clearly due to the hydroxyl ions, being equal in amount when equivalent solutions of hydrates were used, irrespective of the character of the basic ions [see Pflüger's Archiv, 69, 10 (1898)]. The similar effect produced by carbonates of sodium and potassium was ascribed to the same factor, the hydroxyl ions (l. c., p. 20). On the other hand, the effect of sodium carbonate (Na_2CO_3) in stimulating skeleton formation in the pluteus of a sea urchin appears to be due to the carbonic acid (HCO_3) ions, since sodium in other forms, as well as hydroxyl in the form of potassium hydrate, gave negative results [Am. Journ. Physiology, 443, (1900)].

[2] Pfeffer [Pflanzenphysiologie, Ed. 2, 1, 425] observes that possibly chlorides (e. g., sodium chloride), like so many other substances, act in dilute solutions as chemical stimuli. Storp [Biedermann's Centralbl., 13, 76 (1884)] obtained a stimulating effect upon the germination of seeds by immersing them in a 0.01 per cent solution of sodium chloride. Jarius [Landw. Versuchsst., 32, 149 (1886)] found that even a 0.4 per cent solution of sodium chloride stimulated the germination of seeds of wheat, rye, rape, maize, beans, and vetches. Jones and Orton (Bul. Vermont Agric. Exp. Station No. 56, p. 12) observed, as a consequence of the application of sodium chloride to land in order to exterminate the weed known as Orange Hawkweed (*Hieracium aurantiacum*), a marked stimulating effect upon the growth of grass in the same field. Peligot [Comptes rendus, 73, 1078 (1871)] suggests that the stimulating effect upon field crops which is sometimes obtained with sodium chloride may be due to its facilitating the decomposition of calcium phosphate and thus increasing the amount of phosphoric acid at the disposal of the plant. Kellner [Landw. Versuchsst., 32, 365 (1886)] attributes to a similar liberation of phosphoric acid the stimulating effects of iron sulphate upon plant growth recorded by Koenig and by Griffiths (see p. 49). Réveil [De l'action des poisons sur les plantes, p. 41 (1865)] found that sodium hypochlorite in a solution of 0.1 per cent stimulates germination and growth, but is injurious, especially to herbaceous plants, when applied in greater concentration.

Raulin experimented extensively with the fungus Aspergillus as to the effect of various metallic salts in stimulating or hindering its growth, his being among the first considerable work in this line.[1]

The well-known observations of Frank and Krüger[2] indicate that copper in small quantities (furnished by spraying with Bordeaux mixture) stimulates the growth of the potato, acting favorably upon almost every organ and function, although this metal is well known to be extraordinarily poisonous to plants.[1] Miani[2] records the interesting observation that in a vapor-saturated chamber the mere presence of copper in the neighborhood of but not in contact with a hanging drop of water containing spores of Ustilago and pollen grains of various plants stimulated the germination of the latter. H. Schulz[3] found that alcoholic fermentation is accelerated by the presence of a small quantity of mercuric chloride and of other substances. The development of Aspergillus and of Penicillium in glycerol cultures was stimulated, according to Pfeffer,[4] by the presence of small quantities of zinc, manganese, cobalt, etc. Subsequently numerous experiments as to chemical stimulation were made by Richards upon fungi.[5]

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[1] Ann. Sci. Nat., sér. 5, 11, 243 (1869).—The sulphates of zinc and of iron were found to produce marked stimulating effect, the former increasing the dry weight of the fungus two to three or even seven times, the latter about twice. In order to show that the acid radicle was not responsible for the results, a corresponding amount (0.06 gram of salt per 1,000 grams of culture solution) of ammonium sulphate was tried, but no stimulation was obtained. To demonstrate still more completely that basic radicles are here chiefly concerned other salts (nitrates of iron and of zinc, zinc acetate, iron citrate) were tried and yielded stimulative effects similar to those of sulphates. In cases where both iron and zinc were added to the same culture solution (e. g., zinc nitrate plus ferric citrate, or ferric sulphate plus zinc acetate, or zinc acetate plus ferric citrate) the stimulating effect was decidedly more marked than when only one base was used. When sulphates of both zinc and iron were present the effect was nearly twice as great as in the absence of the former, and was exactly twice as great as in the absence of the latter. The diminution of the stimulating effect was almost as great if instead of merely withdrawing one or the other base an equal portion of the second base was substituted for the first; in other words, when two parts of zinc (or of iron) were substituted for one part each of zinc and of iron. The stimulating effect of the different salts of zinc expresses itself in a crop from two to four and six-tenths times, that of iron in a crop one and four-tenths to two and seven-tenths times as great as in the pure culture solution.

Manganese was found to produce effects similar to those of iron and of zinc, but "less constant, less appreciable." Silica (as silicates of potassium and of sodium) when added to the culture solution increased the dry weight of Aspergillus in the ratio of 1.2 or 1.4 to 1.

Raulin wrongly concluded that zinc and silica are indispensable to this fungus, but justly emphasizes "this influence of infinitely small quantities of substances upon vegetation" (l. c., p. 253).

J. Koenig [Landw. Jahrb., 12, 837 (1883)] and Griffiths [Journ. Chem. Soc., 1884, p. 71, and 1885, p. 46] obtained evidence of a stimulating effect of iron sulphate upon the growth of plants by watering soils used in culture experiments with a solution of this salt. On the other hand Kellner [Landw. Versuchsst., 32, 365 (1886)], following the same method of experiment, obtained only negative results.

[2] Ber. d. deutsch. bot. Gesellsch., 12, 8 (1894).

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[1] For a classical discussion of the toxic effect of exceedingly dilute solutions of metallic salts upon the alga Spirogyra, see Nägeli, Neue Denkschr. schweizerischen Gesellsch. f. gesammt. Naturw., 33 (1893). Copper in a solution of 1 part to 1,000,000,000 of water was found to be fatal! (l. c., p. 23.) Attention has lately been redirected to the extreme toxicity of copper by Dehérain et Demoussy [Comptes rendus, 132, 523 (1901)] and by H. Devaux (l. c., p. 717). The latter's observation that protoplasm absorbs less copper when exposed during several hours to a large quantity of a running very dilute solution (e. g., of 1 part copper to 400,000,000 parts water) than when placed for a short time in a single drop of a much more concentrated solution (1 part copper to 30,000 parts water) leaves wholly unexplained the negative results as to the extraordinary toxicity of this substance recorded by Miani [Ber. deutsch. bot. Gesellsch., 19, 461 (1901)], who immersed his subjects for a long period in a single drop of solution. Nägeli's experiments have been more recently repeated (upon Spirogyra and other organisms) by Israel und Klingmann [Virchow's Archiv, 147, 293 (1897)], who made careful studies of the "oligodynamic" effects produced by extremely dilute solutions of copper. A noteworthy contribution to this subject by Galeotti has lately appeared [Biol. Centralbl., 21, 321 (1901)], in which the effect produced by a "colloidal" solution of copper [prepared after the electrical method recently described by Bredig and Müller in Zeitschr. für physik. Chemie, 31, 258 (1899)] is compared with that of an "ionic" solution of copper sulphate containing an equivalent amount of copper. This author found that the former (colloidal) solution plasmolyzed the protoplasm of Spirogyra in a dilution (1 gram-atom copper in 12,600,000 to 126,000,000 liters of water) at which the ionic solution (of copper sulphate) produced no effect whatever. He therefore concludes that the action of the colloidal solution is a catalytic one, closely analogous to the catalyzing action of such colloidal solutions (of copper and other metals) upon hydrogen superoxide.

[2] Ber. deutsch. bot. Gesellsch., 19, 461 (1901).

[3] Pflüger's Archiv f. die gesammte Physiol., 42, 517 (1888).

[4] Jahrb. für wiss. Botanik, 28, 238 (1895).

[5] Ibid., 30, 665 (1897). Richards experimented with sulphate of iron and with salts of zinc, cobalt, nickel, and manganese, as well as other substances, using as subjects one species each of Aspergillus, Botrytis, and Penicillium. The estimation of the amount of stimulus obtained was based upon the increase in dry weight of the whole mass of mycelium in the culture as compared with that in a control free from the stimulating substance. Zinc sulphate was found to be the most powerful stimulant, while important results were also obtained with sulphates of iron, cobalt, and nickel. Salts of lithium were likewise very effective. It was found, however, that acceleration of the development of the mycelium was accompanied by an unfavorable influence upon the production of conidia, when salts of zinc or of iron, amygdaline, or morphine were added to the culture solution. In other words, a stimulation of one function or phase of development does not necessarily imply stimulation of the organism as to all its functions.

Recently an important paper upon the effect of certain chemical stimuli upon fungi and algæ has been published by Ōno.[1]

Similar results as to the stimulation of life processes afforded by the presence of small quantities of various non-nutritive substances have been obtained in experiments with animals. Loeb[2] found this to be true of certain acids, hydrates, and mineral salts, the accelerating effect produced by the solutions upon the absorption of water by muscles, the rhythmical contraction of muscles and the segmentation of eggs being attributed to hydrogen ions, hydroxyl ions, or different basic cathions, as the case may be.[3]

The as yet obscure problem of the mode of action of chemical stimuli as regards plants has been discussed by Pfeffer,[4] from whom it may be permissible to quote at some length:

"In the regulation of activity chemical stimuli certainly play a very extensive part. It is obviously a matter of chemical stimulation that the seeds of Orobanche and of Lathræa germinate only upon the roots of host plants, and probably the same occurs with fungi. In the case of initiatory or only regulatory stimuli, there may be partly involved substances which the organism does not necessarily require. In fact, under certain circumstances very different substances can cause an acceleration of activity. * * * These and similar phenomena obviously arise from different causes. Partly it may be a matter of physiological counter reactions, which can also, for example, occasion an increase of respiration, of circulation of the protoplasm, etc., in response to injurious or other action. In other cases a more simple chemical acceleration of reaction may be concerned, as in catalytic action."

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[1] Journ. Coll. Sci. Univ. Tōkyō, 13, 141 (1900). This author experimented with various species of algæ and fungi in order to determine their reaction to minute quantities of the sulphates of zinc, nickel, iron, and cobalt as well as to sodium fluoride, lithium nitrate, and potassium arsenate. He found a marked increase in the total amount of vegetable matter produced in the presence of any one of these substances, the increase in the case of algæ being due, however, to the stimulation of vegetative reproduction rather than to any marked increase in the size of individual plants. The optimum dose for algæ is considerably smaller than that for fungi, 0.0001 gram molecule in most cases proving toxic to the former. Zinc sulphate exerts the greatest stimulating effect. These salts (especially $ZnSO_4$ and NaFl) tend to hinder the development of spores in fungi. Copper sulphate and mercuric chloride stimulate the growth of fungi, but not of algæ.

[2] See all the papers of this author cited in the Bibliography.

[3] It is probably worth while at this point to call attention to the fact that in nearly every case where this stimulative effect has been observed, electrolytes have been used which are known to show marked hydrolysis, with the formation either of hydroxyl ions, or more generally, as in the case of salts of the heavy metals, of hydrogen ions. And it may well be that, as in the studies of Loeb, the stimulating effects observed by former investigators may rightly be ascribed in the majority of cases to the presence of these ions.

[4] Jahrb. für wiss. Botanik, 28, 238, 239 (1895).

In another work[1] Pfeffer emphasizes the idea of counter reactions, suggesting that "one has to do in this accelerating stimulation with one of the manifold reactions which serve, through more intensive activity, to counteract as far as possible an injurious influence or to compensate injuries." And again:[2] "Probably this [stimulating] effect results from a general reaction of the organism against injurious substances, since similar effects are induced by ether, alkaloids, etc., effects which also find expression in an increase of fermentation and respiration. * * * It is easy to understand * * * that furthermore such substances as are poisonous only in higher concentration generally occasion no obvious [stimulating] effect."

If it can be shown that such stimulating effect is sufficiently permanent to express itself in a marked increase in the yield of a crop, its economic importance would be obvious. That the presence of a certain amount of calcium salts in the soil may really act as a chemical stimulant to growth, apart from the value of the salts as plant food, or in rendering soluble other nutritive soil components there appears to be some reason to believe. It is not impossible that other substances, even perhaps those salts of magnesium and of sodium which constitute the most noxious components of alkali soils, when present in quantity too small to be harmful, may be actively stimulative rather than merely indifferent to plants. That several of them are likewise valuable as sources of nutritive material is well known. Whether, after all, the distinction between the chemically stimulating effect and the utility as food of certain mineral salts be always as sharp as is commonly supposed, is a question which can not yet be regarded as decisively answered.

ECONOMIC IMPORTANCE OF THE RESULTS.

Some of the facts ascertained by these experiments with salt solutions in their effect upon plants have a direct practical bearing upon agricultural conditions and methods in regions where alkali salts are frequent. Attention is particularly directed to the effects obtained by the addition of lime salts to others. Each of the common soluble alkali salts is found to be very injurious when alone, but usually much less harmful when two are mixed, especially when a salt of lime is one component of the mixture. This is strikingly the case with sulphates of magnesium and of sodium, the noxious effects of these salts being enormously lessened by the application of lime, particularly in the form of gypsum or land plaster (the dihydrate of calcium sulphate). Contrary to the general impression, this corrective effect was found in water-culture experiments to be considerably less for "black alkali" (sodium carbonate) than for any of the "white alkali" salts, although even the harmfulness of black alkali can certainly be greatly diminished by the use of gypsum.

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[1] Pflanzenphysiologie (Zweite Auflage), 1, 374 (1897).

[2] Ibid., p. 409.

The soluble chloride of lime could apparently also be used to advantage upon a soil which is strongly impregnated with alkali. With this salt the best effects would be anticipated when it is used as a remedy for black alkali, although it is likewise a powerful antidote for the chloride and sulphate of soda and of magnesia. But, except in rare instances, the use of chloride of lime upon a large scale is hardly practicable. The little-soluble carbonate of lime is likewise more or less beneficial in all cases except that of black alkali, but it is a much less powerful remedy than is land plaster (calcium sulphate).

Much economic value should attach to an extension of these experiments by using mixtures of more than two salts. It would thus be possible to imitate more closely the conditions which obtain in alkali soils, where several or all of these salts usually occur together. Furthermore, other kinds of plants should be tried in order to determine to what extent plants differ one from another in their power to resist the effect of various combinations of alkali salts. In this connection experiments should be made with wheat, barley, sugar beets, and other important crops of the region, as it may be found that one crop is better adapted than another to withstand the effects of this or that type of alkali soil.

This leads to the possibility of selecting alkali-resistant breeds of each of the leading crops. By observation of a stand of wheat or of alfalfa which has been injured by the "rise of alkali" or by the use of alkaline irrigating water, it is usually possible to find here and there individual plants which have succeeded in surviving the injurious effects of the salts. Similar differences in the power of individuals to resist the action of alkali salts was detected in the culture experiments. By continued selection of the seed of such resistant individuals, sowing it season after season in alkali soil, there is reason to hope that in time a race could be developed and fixed which would flourish in soils containing a greater amount of alkali than can be endured by the ordinary agricultural varieties.[1] It will likewise be very interesting to determine whether a race bred to resist black alkali, for example, will also prove to be proportionately resistant to white alkali, or whether it will be possible and desirable to develop different races to suit different types of alkali soil. An observation already cited (see p. 34) would indicate that the different power of resistance possessed by individuals of the same species of plant is brought out more sharply in the presence of the carbonates of soda than when other "alkali" salts are concerned.

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[1] Observations made by Roos, Rousseaux, and Dugast [Ann. de la Science Agron., sér. 2, 6ième année, 2, 336 (1900)] indicate such differences among the grapes cultivated in Algeria. It was found that of different varieties growing in the same soil the fruit of some absorbed less sodium chloride from the soil than was taken up by others. As the sale of wine containing too high a content of sodium chloride is prohibited by law in France, the economic importance of this discovery is obvious. Although the problem here involved is somewhat different from that of the power of resistance to the poisonous effects of a salt upon the plant, it serves to illustrate the general principle that different individuals or races show marked dissimilarity in their behavior in the presence of a given soil component.

So great appears to be the promise of results to be obtained by breeding alkali-resistant races of the more important field crops of the far western United States, that the Department of Agriculture has already undertaken work on this line. During the past season experiments with this end in view were begun under the direction of Mr. Webber, of the Plant-Breeding Laboratory, Division of Vegetable Physiology and Pathology. It is hoped that they will demonstrate the practical value of this method of approaching the problem.

SUMMARY.

As the result of these preliminary studies, the following facts can be regarded as established:

(1) Those readily soluble salts of magnesium and of sodium which are characteristic components of alkali soils are exceedingly injurious to plants when exposed to pure solutions of them of concentration above a minimum which is specific for each.

(2) They are toxic in the following sequence, beginning with the most harmful: Magnesium sulphate, magnesium chloride, sodium carbonate, sodium sulphate, sodium chloride, and sodium bicarbonate.

(3) Calcium chloride in pure solution is ten times less injurious than sodium chloride, and two hundred times less injurious than magnesium sulphate, if chemically equivalent solutions are considered.

(4) Magnesium carbonate in a saturated solution is not markedly injurious, while magnesium bicarbonate in saturated solution acts as a strong poison. Calcium carbonate and calcium sulphate are positively stimulating in saturated solutions, while calcium bicarbonate appears to be decidedly injurious.

(5) The toxic effect of the injurious salts is due very much more to the influence of the cathions (derived from the basic radicle) than to the anions (furnished by the acid radicle).

(6) By mixture of equal volumes of two readily soluble salts, or by the addition of a solid excess of a relatively insoluble to a solution of an easily soluble salt, the toxic effect of the more harmful component can in a majority of cases be diminished, or the concentration of the more toxic salt endurable by the roots of plants can be increased.

(7) This increase is much greater in cases where a different kind of cathion is added to the solution than when a new anion only is introduced.

(8) Addition of sodium ions to a solution containing magnesium ions in most instances markedly weakens the toxic action of the latter.

(9) Addition of calcium ions to solutions containing either sodium or magnesium ions nearly always counteracts to an extraordinary degree the injurious effect of the sodium or magnesium ions, this beneficial influence being usually much more marked when calcium is furnished as the sulphate than when the chloride is added.

(10) The ameliorating effect of calcium sulphate is much more marked when it is added to sulphates of magnesium and of sodium than when it is mixed with the corresponding chloride. It raises the concentration limit endurable by plant roots in magnesium sulphate four hundred and eighty times, in sodium sulphate more than sixty times.

(11) Even plasmolysis, although supposedly a reaction to purely physical stimuli, can apparently be completely prevented by altering the chemical nature of a solution without materially diminishing its osmotic pressure. At any rate, plasmolysis was not detected in cases where a solid excess of calcium sulphate had been added to a 0.3 or even 0.4 normal solution of magnesium sulphate, although a pure solution of magnesium sulphate is very strongly plasmolyzing at the concentrations named.

(12) Calcium chloride appears to be peculiarly effective in neutralizing the effect of sodium carbonate.

(13) The effect of one kind of ion in counteracting the physiological action of another kind can not be entirely explained by a study of the chemistry of the solution itself, but must in part be referred to complicated changes in the protoplasm of the organisms. The theory that ions furnished by the dissociation of electrolytes form intimate combinations with the proteids of protoplasm, and that their mutually antagonistic effect expresses itself in a replacement of one kind of ion by another as a result of change in the composition of the surrounding solution, would appear to afford the key to this problem.

(14) At a certain degree of dilution all of these salts become indifferent (i. e., neither toxic nor stimulating) in their action upon plant tissues. The maximum concentration of the indifferent solution is likewise specific for each salt.

(15) At a still greater dilution some of them, as the salts of calcium and the two carbonates of sodium, produce a positively stimulating effect upon the growth of roots.

(16) Individual plants show a marked dissimilarity in their power of resistance to the toxic action of the alkali salts. Such individual differences are strikingly accentuated in solutions of sodium carbonate and of sodium bicarbonate of the maximum concentration which will permit any of the roots to retain their vitality.

CONCLUSION.

Too great stress can not be laid upon the fact that the experiments upon which the present report is based are merely preliminary. Furthermore, they were designed primarily to afford a standard for comparison of the salts involved. It is not to be expected—indeed, it is assuredly not true—that in the soils containing these salts the conditions are quite comparable to those maintained in the laboratory in the course of these investigations. The physical nature of the soil, as well as the presence of various other soluble substances, renders it certain that nowhere in the field will these salts be found to have anything like the poisonous effect which they severally exert upon the roots of plants immersed in water solutions. Nevertheless it is only from such experiments, conducted under simplified conditions, that we can draw conclusions as to the actual effect of the components of alkali soils upon plant growth.

It is very desirable that this line of investigation be continued and extended. Further combinations, perhaps of more than two salts, should be tested; an attempt should be made to imitate as closely as possible natural soil conditions; plants in different stages of growth should be tried, for in irrigated regions it often happens that a standing crop is exposed to a varying soil content of soluble salts at different periods of its development. Finally, it is highly important that the experiments be repeated with other plants of widely different relationship and, as far as possible, of actual agricultural importance in the region concerned. For while we may assume for the present that the same sequence of harmfulness of the several salts will obtain in the case of most or all ordinarily cultivated plants, this is open to doubt, and it is quite certain that the actual limits of endurance differ in the case of different plants.

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[1] An extensive bibliography of the earlier literature of the subject is given by this author (pp. 169 to 176).

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FORMATION OF SODIUM CARBONATE, OR BLACK ALKALI, BY PLANTS.

By Frank K. Cameron.

INTRODUCTION.

Considerable attention has been paid within the past few years to the possibility of growing valuable forage crops on some of the alkali soils of the arid West. This subject was first taken up in California.[1] The great value of saltbushes for certain soil conditions and for certain kinds of cattle feeding seems to be well established, but as both Hilgard and Goss[2] have pointed out there is an element of danger, expressed in the prevalent belief that most of these plants, including the greasewood, chico, and other indigenous plants, convert the less harmful neutral salts, such as sodium chloride and sodium sulphate, into alkali carbonates—that is to say, the less harmful "white alkali" is converted into the more noxious "black alkali," as has been shown by the presence of sodium carbonate immediately under such plants, whereas no trace of it exists some distance away. It may be possible that the plants with their enormous root systems actually gather up minute traces of sodium carbonate, which may be present in lower depths of soil, gradually causing an accumulation at the surface on the decay of their roots and branches. But the generally accepted hypothesis of the conversion of the neutral salts appears more probable, as will be seen in the course of this paper. It would seem probable that plants growing in bunches or mats would be more effective in producing these localized black-alkali spots, but some of the most striking illustrations of this phenomenon have been observed in connection with more upright species, such as *Sarcobatus vermiculatus*, the common "greasewood" of the West.

In the study of the alkali soils of the arid regions the field parties of the Division of Soils have found the local flora of great value in indicating the character of the particular soils where they are found. This apparent relation between the plant and the salts present in the soil became of interest in this connection and was referred to the laboratory for consideration. The results of some preliminary investigations have proved of such interest as to warrant immediate publication.

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[1] University of California, Agricultural Experiment Station, Bul. No. 125 (1899).

[2] New Mexico College of Agriculture and Mechanical Arts, Agricultural Experiment Station, Bul. No. 22, p. 41 (1897).

CREOSOTE BUSH.

A specimen of the creosote bush[1] (*Covillea tridentata*) was examined. This, while a desert plant, is said to shun soils where there is much water-soluble salts. Mr. Means states that its presence can be taken as a sure indication of land free from injurious quantities of alkali. It is found in dry, well-drained upland soils.

The material was thoroughly air dried. The leaves and stems were then carefully separated, and both of the separated samples were ground fine in an agate mortar. A portion of each sample was burned to ash. The finely ground air-dried material and the ash were each carefully leached with successive small portions of water until the leachings ceased to show the presence of chlorides. The leachings in each case were then brought together and made up to a volume of 500 cubic centimeters, and the various determinations were made with 100 cubic centimeter portions. The carbonates[2] were determined by titrating with a twentieth normal (N/20) solution of hydrogen potassium sulphate until loss of color, using phenolphthaleine as indicator. So soon as the color had disappeared a drop or two of a solution of potassium chromate was added and the chlorine determined by titrating with a tenth normal (N/10) solution of silver nitrate. The sulphates, when determined, were estimated gravimetrically as barium sulphate in the usual manner. For convenience the acids thus found to be present are stated as the corresponding sodium salts. This procedure seemed to be justified by a subsequent determination of the amount of sodium present in the solution. It is a well established fact, and a familiar one to chemists, that when a salt of an alkali metal is burned down with charcoal or other organic matter a part of the mineral acid is volatilized and driven off, the alkali base forming a carbonate, which is a stable compound even at quite high temperatures. Nevertheless this is a point often overlooked in the discussion of ash analyses. In obtaining the ashes the examinations of which are described in this paper, very great care was exercised to reduce the amount of this loss of the mineral acid as far as possible, and the burning was done at as low a temperature as possible. In some cases the large amount of fused salt in the burning ash coated the charred organic matter in such a way as to render further combustion at a comparatively low temperature quite impossible. In these cases the combustion was stopped, the fused salts leached out with water, and the residue reburned. It seems probable, as will appear from the results which will be presented, that the loss of mineral acids in the burning of the plant to ash was kept down to a very small percentage by following the procedure described.

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[1] Collected by Mr. Thos. H. Means near Tempe, Ariz.; kindly identified for us by Mr. F. V. Coville.

[2] Report 64, Division of Soils, U. S. Dept. Agr. (1900); Amer. Chem. Jour., 23, 571 (1900). Bul. 18, p. 77, Division of Soils, U. S. Department of Agriculture (1901).

The data obtained on examination of the ashes from the creosote bush are presented in the following table:

TABLE XII.—*Analysis of the ash of the creosote bush.*

	Leaves.	Leaves and small stems.	Stems.
Weight of sample, grams	8.5659	3.6942	6.6445
Weight of ash, grams	.8282	.3795	.3710
Ash, per cent of plant	9.66	10.27	5.58
Na_2CO_3, per cent of ash	8.90	13.18	17.73
NaCl, per cent of ash	5.71	5.37	3.55
Na_2CO_3, per cent of air-dried plant	.86	1.35	.99
NaCl, per cent of air-dried plant	.55	.55	.19

The dry leaves, which had been ground fine in a mortar, were extracted with distilled water at the room temperature in the manner described above. The extract failed to show the presence of either sodium carbonate or sodium chloride, but appeared to be slightly acid. An extract made by boiling the leaves with water also failed to show any chlorides or carbonates.

From the facts which have been presented it would appear that while the plant does contain chlorine there is no sodium chloride present as such, and therefore it is probable that the chlorine is in organic combination although nothing is definitely known of the presence of such combinations in plants. The sodium is largely in excess of the amount required to balance the chlorine as sodium chloride. This fact was shown by an actual determination of the sodium.[1] It would seem, therefore, that at least a large part of the sodium in the plant is in organic combination, possibly with some organic acid, and, on combustion or ultimate decay of the plant tissues, much sodium carbonate would be formed, as was found to be the case when the plant was reduced to ash in the laboratory.

It is interesting to note that the mineral constituents, as shown by the ash analyses, had accumulated in the leaves to about twice the amount in which they were held by the stems. The difference is very much less, however, if we consider only the water-soluble constituents in the ashes. Assuming, for the sake of argument, that the base in combination with the carbonic acid and chlorine as determined was entirely sodium, its distribution is shown by the following table:

TABLE XIII.—*Distribution of sodium in leaves and stems.*

Part of plant.	Percentages calculated for ash.			Percentages calculated for air-dried plant.		
	From Na_2CO_3.	From NaCl.	Total.	From Na_2CO_3.	From NaCl.	Total.
Leaves	3.86	2.25	6.11	0.37	0.22	0.59
Stems	7.69	1.40	9.09	.43	.07	.50

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[1] Unfortunately it was not anticipated at the time this determination was made that the exact figure would be required in this discussion, and the data were not entered in the laboratory notebook and have been mislaid.

It appears that in the leaves there was about 2.7 times as much sodium as was necessary to balance the chlorine, while in the stems there was more than seven times as much of the base as the acid would require. This suggests the possibility that the chlorine was being eliminated through the leaves, probably in the form of some volatile compound, which may be the source of the odor from the plant. This idea is brought out somewhat more strikingly, perhaps, by noting that the analytical figures given above indicate that the total amount of water-soluble mineral constituents in the leaves is 1.19 times the amount in the stems, but that the amount of chlorine in the leaves is 2.75 times that found in the stems; from which it would appear that the chlorine was being concentrated in the leaves and, as has been pointed out, was there present, in all probability, in organic combination. This is a point which merits further attention, and it is hoped that it will be the subject of a more thorough investigation in the future.

GREASEWOOD.

A more thorough examination of a specimen of greasewood[1] (*Sarcobatus vermiculatus*) was made. This is a typical "alkali plant," its presence being usually regarded as a good indication of much water-soluble material in the soil. Mr. Means reports that whenever he has observed it the soil generally shows the presence of sodium carbonate, the only exception being in Montana, where the soluble salts are entirely sulphates. It would appear that this latter statement warrants further examination of the locality mentioned.

The analytical results obtained from examination of the ashes follow:

TABLE XIV.—*Analysis of the ash of the greasewood plant.*

	Leaves[1] and blossoms (1).	Leaves and blossoms (2).	Stems.
Weight of sample, grams	10.6395	5.0000	10.6817
Weight of ash, grams	2.7505	1.1736	.5274
Ash, per cent of plant	25.85	23.47	4.94
Na_2CO_3, per cent of ash	51.93	57.90	29.46
NaCl, per cent of ash	20.47	22.24	14.31
Na_2SO_4, per cent of ash	7.97	....	3.69
Na_2CO_3, per cent of air-dried plant	13.43	13.69	1.45
NaCl, per cent of air-dried plant	5.29	5.22	.71
Na_2SO_4, per cent of air dried plant	2.06	....	1.18

[1] Owing to the relatively large amount of fused salts which coated the carbon or other organic matter, this latter could not be completely burned off when reducing such a large sample to ash.

Five grams of leaves and blossoms, by successive leachings with distilled water at room temperature until the leachings aggregated 2 liters, gave (1) 5.81 and (2) 5.68 per cent of sodium chloride. In both experiments the washings showed no trace of soluble carbonates, but were slightly acid. The residue from (1) after ignition gave a trace of sodium chloride and 0.04 per cent of sodium carbonate.

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[1] Collected by Mr. Frank D. Gardner near Salt Lake, Utah.

By the method of Carius—that is, heating in sealed tubes with fuming nitric acid and silver nitrate—

(1) 0.2327 gram of leaves and blossoms gave 0.0310 gram AgCl, equivalent to 5.43 per cent of sodium chloride.

(2) 1.0759 grams of leaves and blossoms gave 0.1432 gram AgCl, equivalent to 5.43 per cent of sodium chloride.

From these results it would appear that the plant contains chlorine, but, within the limits of experimental error, all the chlorine is present as sodium chloride, which can be leached out with water at ordinary temperatures. This is probably true of the major part of the sulphates also, although this was not shown quantitatively. A striking feature is the much larger amount of ash from the leaves and blossoms than from the stems and the markedly larger percentage of the alkali salts in the ash of the former. The idea suggests itself that possibly this plant takes up and stores the salts and holds them as such until it is ready to use such part of them as it needs.[1] On the other hand, it may be, for all that we now know, that these salts are present as described only because the plants can not prevent their accumulation, and, so far from being an inherent feature of the plant's economy, it may be a most undesirable accident due to their peculiar environment, but an accident in spite of which these particular plants are able to survive.[2] But, as Schimper[3] has pointed out, this can not be true in all cases, as evidenced by the fact that halophilous plants show a tendency to take up more salts than nonhalophilous species, even when grown in nonsaline soils.

None of the chlorine, apparently, was in organic combination, this plant being in striking contrast in this respect to the *Covillea tridentata* examined above.

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[1] Schimper [Indomalayische Strandflora, p. 12 (1891); Pflanzen-Geographie, p. 99 (1898)] has expressed the opinion that halophytes thrive on salty soils because of a peculiar physiological structure which enables them to reduce to a minimum the evaporation from their leaves and, in consequence, the absorption of the salt solutions in the soil through their roots. The salt content of their sap is thus kept below a certain concentration, although this concentration may, and often does, greatly exceed that which would be determined by "osmotic equilibrium."

Stahl [Bot. Zeitung, p. 139 (1894)] observes that only a few species, such as *Reaumuria hirtella*, described by Volkens [Die Flora der Aegyptisch-Arabischen Wüste, p. 27 (1887)], are known to be able to free themselves from the salt.

Diels [Jahrb. für wiss. Botanique, 32, 316 (1898)] objects that Stahl experimented with cultivated plants and that the retarded root action noted by Schimper does not take place under natural conditions, and that, as a matter of fact, and probably through the agency of malic acid, most, if not all, the halophytes rid themselves of an excess of chloride. Diel's methods of experiment, as well as the conclusions which he draws from his own premises, are criticized by W. Beneke, Jahrb. für wiss. Botanique 36, 179 (1901).

Directly bearing upon this hypothesis is an observation by Detmer [Bot. Zeitung, 42, 791 (1884)] that "organic acids under the condition prevailing for the vegetable organism are in a position to decompose chlorides with a formation of free hydrochloric acid." See also, Osborne, Report Conn. Ag. Ex. St., 1900, p. 441.

[2] Contejean, Geog. Bot., p. 71.

[3] Schimper, Pflanzengeographie, p. 101 (1898).

Another interesting point is that the leachings of the air-dried leaves and blossoms must have contained about three times as much sodium as was necessary to balance the hydrochloric and sulphuric acids present in the plant. The total amount of sodium calculated from the ash analysis would be 8.32 per cent. A direct determination of the sodium made on an aliquot part of the leachings gave 8.55 per cent, while the amount calculated as necessary to balance the hydrochloric and sulphuric acids, as determined by the ash analysis, is 2.68 per cent. The residue after leaching contained practically no chlorine, sulphates, or carbonates. It would appear that in the burning of the plant or in its decay the sodium, which is probably present in organic combination, yields sodium carbonate as a decomposition product, and this in turn is found in the ash or débris. It seems probable that a large part of the chlorine which was originally taken up or at least held by the plant in the form of sodium chloride has been thrown off by the plant in some manner, the sodium being retained in organic combination.

ABSORPTION OF MINERAL CONSTITUENTS BY THE PLANT.

Inspection of the analyses of the ashes of plants in general, whether leaves, stems, or in fact any part of the plant tissues, shows that there are more than enough base-forming elements to counterbalance the possible inorganic acids which the results indicate to be present. Moreover, the ashes are alkaline. It is still an open question as to how these bases, which appear in excess, or, more generally, how all the bases, are taken up and assimilated by the plants and what becomes of the acid radicals. While it is possible that some of the alkaline materials may have been absorbed by the plant in the form of carbonates as such, the amount thus absorbed will be relatively very little, for by obvious metathetical reactions or double decompositions there would be formed carbonates of the alkaline metals. These latter would be hydrolized in water to some extent, giving caustic solutions which would undoubtedly corrode the tissues of the plants. The question as to the disposition of the acid residues is then pertinent. Several possible explanations suggest themselves, which seem worthy of attention in this connection.

It is possible that chlorine, for example, which may have been in the acid radical, has been changed by the plant in such a way as to form organic substances, and that these organic substances may be exhaled by the plant as odors or exuded by the leaves or roots. Against the latter suggestion the experiments of Diels[1] indicate that the excretion of such substances by the roots is very improbable. On the other hand, the chlorine or sulphur may be retained in the plant tissues in organic combination in such form that they more or less completely disappear on combustion, the organic combination volatilizing as such, or by decomposition yielding volatile products containing the chlorine or sulphur.[1] In evidence against this view are the results obtained in the examination of the sample of *Sarcobatus vermiculatus*, where it was found that the total amount of chlorine in the plant, as determined by the Carius method, in which there was afforded no opportunity for any of the chlorine to escape, was the same as the amount leached out of the ashes by water, within the limits of experimental error.

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[1] Jahrb. für wiss. Botanique, 32, 316 (1898).

Another idea that presents itself is that the bases and acids are taken up by the plant in the form of salt solutions; that the plant selects and retains the bases and excretes the acid radicals in some manner as acids. It is noteworthy, in this connection, that it has been observed generally in the cases of water cultures that the nutrient solutions gradually become acid unless special conditions are introduced to prevent it. Occasionally, however, cases have been found where the culture solutions actually become alkaline.[2] The point of special importance in this connection is that either a base or an acid radical, more often the latter, is either rejected or ejected by the plant.

It seems to have been generally supposed that the acidity of these solutions was due to organic acids formed and excreted by the plant, but no satisfactory proof for this view has been adduced. The weight of evidence is now decidedly against this view. It is not at all difficult, from the point of view of the chemist, to construct a probable "mechanism" for the phenomena presented, supposing that the plant has selectively retained the basic constituents and excreted the acids, and that the acidity of the culture solutions is due to the free mineral acids. Diels's[3] investigations in this direction are particularly interesting. He found that certain halophilous plants, when placed in distilled water, steadily lost the sodium chloride they contained. He showed that the salt was not excreted as such,[4] and offers as a probable explanation that the greater amounts of malic acid—the formation of which is shown to be a usual accompaniment of growth in succulent plants, such as most of the halophytes are—decomposes the sodium chloride, forming sodium malate and hydrochloric acid, and this latter is possibly excreted by the roots.[5] The solutions become acid, but, on account of the experimental difficulties, it was not definitely proved that the acidity was due to the presence of hydrochloric acid. It is intended that some experiments in this direction shall soon be made in the laboratory.

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[1] It is not intended to imply that chlorine and sulphur may not play very different parts in the plant economy, but the general considerations advanced might be true for either of these or other elements.

[2] Witness the classical investigations of Stohmann, Sachs, and Knop, described by Johnson in How Crops Grow, p. 180.

[3] Loc. cit. See also Kearney, Contributions from U. S. National Herbarium, Vol. V, No. 5, p. 277 (1900); and Benecke, Jahrb. für. wiss. Botanique, 36, 179 (1901).

[4] This point was established as early as 1865 by Wolf, Landw. Versuchstt., 7 pp. 20, 211 (1865).

[5] See reference to Benecke on p. 64.

A somewhat simpler explanation than the one just described may be offered—simpler because it does not require that the plant must first take up the acid radical and then go through the reverse process of exuding it again. It is known with reasonable certainty that a certain amount of hydrolysis takes place in aqueous salt solutions, although the absolute amount may be, and with ordinary strong electrolytes usually is, very small indeed; nevertheless, it does take place to some extent, and it seems not impossible that the plants might show their selective properties in the solution, taking up the base more rapidly than the acid, the latter in consequence being left in greater proportion in the culture or soil solution. Of classical importance in this connection is the work of Kuhn,[1] who found that when maize was grown in a solution containing ammonium chloride, the ammonium residue was partly taken up by the plant and hydrochloric acid remained in the solution. In fact, there does not seem to be any inherent difficulty in supposing that the plant might selectively absorb any ion for which it might have a special predilection. As soon as this ion is removed from the solution the corresponding ion with its opposite charge of electricity must either be removed from the solution by precipitation or volatilization, for example, or it at once reacts with the water. Supposing the ion removed by the plant to be a base, the action of the remaining acid ion on the water must necessarily be accompanied by the liberation of oxygen from the water of the solution. Whether or not any observation of this kind has been made I do not know, but the liberation of the oxygen might very well take place so slowly as to escape detection. The question as to what becomes of the electrical energy on the ion which the plant absorbs will be answered in a consideration of the work energy, heat energy, or other equivalent forms of energy involved in the mechanism of the absorption process, and does not necessarily demand further consideration at this point.[2]

It must be admitted in all frankness that the known facts in our possession are not sufficient to justify a positive opinion as to the views just presented. They seem, however, to be founded on a rational basis and are put forward tentatively as suggestive of possible lines of investigation and the justification for formulating them here will be found in the results of future work. Whatever may be the bearing of this work on the ideas here presented, it can not fail to be of the utmost importance in throwing light upon the difficult problem of plant nutrition.

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[1] Henneberg's Journal, pp. 116 and 135 (1864).

[2] These views are not intended to imply that salts can not be taken up as such, even by nonhalophilous plants, under certain conditions. Wolf (loc. cit.) has long since shown that this may be done, and that, moreover, in such cases the process can not be a simple diffusion phenomenon.

From the data presented above it is evident that in the decay of wood or leaves or, in general, of plant tissues, alkaline carbonates are furnished to the soil. It may be that the processes of decay will furnish at the same time organic acids stronger than carbonic acid and in sufficient quantity to combine with all the bases and prevent an alkaline reaction. As has been shown in this laboratory carbonic acid itself may be formed in sufficient amounts to convert all the carbonates to the form of bicarbonates and thus prevent an alkaline reaction. There is not sufficient evidence to justify a positive statement, but it would seem probable that this can not be always the case and that in fact there is alkali formed by the decay of plant tissues. In humid regions the alkali thus formed is removed by leaching or similar processes and by chemical reactions with the other soil components, for which reactions water is necessary.

In the arid regions, such as are found in the western part of the United States, peculiar phenomena, due to the special conditions there existing, have been observed. The indigenous plants which are found on the alkali lands are comparatively few in number, both as to species and as to individuals; others have been artificially introduced. They all have the property of absorbing more or less large amounts of water-soluble mineral salts and on analysis all show characteristically large percentages of bases. When the leaves or débris from these plants have decomposed there is often found greater or less accumulation of carbonates, although before the plant was cultivated that particular region may have been quite free from soluble carbonates. The decay of any organic matter with the accompanying formation of carbonic acid in a soil containing soluble salts of the alkali metals must be expected to result in the formation of soluble carbonates, partly by dissolving lime or magnesium compounds, followed by subsequent metathetical reactions or double decompositions with the alkali salts; more slowly and in lesser degree, perhaps, but nevertheless surely, if the formation of carbon dioxide is continued, by a distribution of the base between the two acids. This last process, however, is probably of decidedly minor importance in the phenomena under consideration.

Owing to the conditions of climate and drainage existing in the arid regions these carbonates when formed are not leached away, as in the humid regions, and gradually accumulate to the more serious detriment of the soil.

COMPARISON OF ANALYSES.

For the purpose of comparison, two analyses of greasewood (*Sarcobatus vermiculatus*) ash are here quoted, the first published by Hilgard,[1] and the other by Goss and Griffin.[2]

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[1] University of California, Report of Agr. Exp. Sta., p. 142 (1890).

[2] New Mexico College of Agr. and Mech. Arts, Agr. Exp. Sta., Bul. 22, p. 41 (1897).

TABLE XV.—*Two analyses of ash of greasewood plant.*

Constituents.	First analysis.	Second analysis.
	Per cent.	*Per cent.*
Ash of air-dried plants	12.03	13.12
SiO_2	11.81	3.00
K_2O	18.53	22.06
Na_2O	39.45	23.89
CaO	1.36	6.52
MgO	1.09	1.35
MnO_2		Trace.
Fe_2O_3	7.06	[1] 4.73
Al_2O_3		
P_2O_5	3.51	4.12
SO_3	4.93	4.33
CO_2	0.46	23.80
Cl	15.04	8.01
	103.04	101.81
Oxygen = chlorine	3.25	1.81
	99.79	100.00

[1] By difference.

While these analyses differ considerably in details they indicate the same general conclusions; that is, the ash or decomposition products of the plant will yield a very large amount of alkali in the form of carbonates. The figures in Hilgard's analysis, he states, indicate the presence of about 25 per cent of sodium chloride; about 8 per cent of Glauber's salt ($Na_2SO_4 10H_2O$), and about 39 per cent sodium carbonate. Combining the figures of Goss and Griffin's analysis in the conventional way, we find about 13 per cent sodium chloride and 29 per cent sodium carbonate. The figures are misleading, for they depend upon an arbitrary calculation of the data as salts, and the effect of the other constituents can not properly be ignored. Similarly, but a qualitative comparison can be made from the data obtained by us. If it may be assumed that the leaves and stems are of equal mass in the individual plants when air dried, our results compare quite well with the analyses just cited.

Acknowledgments are due Messrs. F. D. Gardner and Atherton Seidell for assistance in the experimental work described.

SUMMARY.

It would seem as a result of the experiments described in this paper that in certain cases at least a transformation of neutral salts to the corresponding carbonates through the agency of plant growth is possible and even probable, and that this factor must be taken under consideration in determining the value and use of such plants. Some tentative suggestions are offered as to the disposition of the mineral salts in plant economy, which it is hoped will lead to more exhaustive investigations.

RESISTANCE TO BLACK ALKALI BY CERTAIN PLANTS.

By Frank K. Cameron.

INTRODUCTION.

While working in the San Joaquin Valley, California, during this past summer one of the field parties of the Division of Soils observed three species of plants which appeared to be characteristic growths on soils containing much "black alkali" or sodium carbonate. Superficial examination in the field brought out the fact that the stems and leaves of these three plants were quite acid, in some cases very markedly so. A possible connection was suggested between this fact and the one first noted—that these plants were all found on soils containing much sodium carbonate. Specimens were collected and sent in to the laboratory for further examination. They were kindly identified by Mr. Kearney, of the Division of Vegetable Physiology and Pathology. They consisted of three samples of *Distichlis spicata*, numbered I, II, and III; one sample of *Suaeda intermedia*, which was separated into two portions, the first numbered IV, consisting of the stems alone, and the second numbered V, being composed of leaves alone; one sample of *Atriplex bracteosa*, which was also separated into a portion numbered VI, consisting of stems alone, and a portion numbered VII, consisting of leaves alone.

Samples I, II, and III were thoroughly air dried by being allowed to remain for about two months in the sacks in which they were received at the laboratory. It should be stated that a rough determination of the acidity they displayed was made as soon as they were received in the laboratory, and the results agreed fairly well with those obtained by the more careful examination subsequently made.

Samples IV, V, VI, and VII were found to be very wet and in serious danger of fermenting when received at the laboratory. They were therefore placed in a hot-air oven and dried for several days at from 105° to 110°C. In each case the material was then cut into small pieces and kept in carefully covered beakers, to which, however, the air had free access.

METHOD OF EXAMINATION.

The method of examination was in all cases to steep the sample, which had been cut into small pieces about a centimeter in length, overnight or for about twenty hours in a convenient amount of distilled water. About 600 cubic centimeters of the supernatant solution was then decanted through a folded filter, and the analytical details carried out with 100 cubic centimeter portions of the filtered liquid. It was thought probable that this procedure would give a close approximation to the soluble salts on the plant or held in its tissues in the form of inorganic salts. The acid material on the surface of the plant was evidently quite soluble in water. It was concluded, as will be shown later, that it was an organic acid, and that in all probability considerable quantities of its sodium or other salts, as well as the acid itself, were on the surface of the plant and dissolved in the water. The amount of free acid was determined by titrating with a solution of potassium hydroxide, which in turn had been carefully standardized by titration against a twentieth normal (N/20) solution of acid potassium sulphate. The other determinations were made in the conventional way.

DISTICHLIS SPICATA.

TABLE XVI.—*Distichlis spicata.*

	Sample I.		Sample II.		Sample III.	
Grams of material	13.12		35.35		29.48	
Cubic centimeters of leachings	750		1,250		1,500	
Percentage (mineral matter) leached out	4.52		5.12		5.73	
Cubic centimeters N/20 acid equivalent to 1 gram substance	23.08		1.16		2.48	
	Percentage distribution.	Per cent in air-dried material.	Percentage distribution.	Per cent in air-dried material.	Percentage distribution.	Per cent in air-dried material.
Ca	5.62	0.254	2.89	0.148	3.25	0.186
Mg	1.86	.084	1.17	.060	2.10	.120
Na	41.30	1.867	33.12	1.696	27.24	1.561
K	13.40	.606	9.70	.497	12.23	.701
SO_4	4.38	.198	4.69	.240	2.72	.156
Cl	33.44	1.511	48.43	2.480	52.46	3.006
	100.00	4.520	100.00	5.120	100.00	5.730
$CaSO_4$	6.19	.280	6.64	.340	3.83	.219
$CaCl_2$	10.48	.474	2.58	.132	5.90	.338
$MgCl_2$	7.25	.328	4.57	.234	8.20	.470
KCl	25.52	1.154	18.49	.947	23.27	1.333
NaCl	15.22	.688	57.08	2.922	52.03	2.981
Na	35.34	1.598	10.64	.545	6.77	.388
	100.00	4.520	100.00	5.120	100.00	5.730

TABLE XVII.—*Soil (0–12 inches) in which Sample I of Distichlis spicata was found.*

	Per cent.		Per cent.
Ca	0.48	$CaSO_4$	1.60
Mg	.16	$MgSO_4$	.75
Na	33.77	Na_2SO_4	5.50
K	1.81	KCl	3.47
SO_4	5.44	NaCl	10.72
Cl	8.06	Na_2CO_3	39.96
CO_3	22.63	$NaHCO_3$	38.00
HCO_3	27.65		
			100.00
	100.00	Percentage soluble, 1 gram soil to 20 cubic centimeters water	3.73

The analytical data obtained from an examination of the *Distichlis spicata*—Samples I, II, and III—are given in Table XVI. The most striking point brought out is the very large amount of acid shown to be on Sample I, amounting for 1 gram of the air-dried material to the equivalent of 23 cubic centimeters of a twentieth normal (N/20) acid. This substance was unquestionably an organic acid and a fairly strong one. It did not appear to act on crystals of calcite very readily. This might have been due, however, to the formation of a slightly soluble lime salt, which would protect the calcite from the solvent. The acid very readily decomposed the alkali carbonates and neutralized not only ammonium hydrate but potassium or sodium hydroxide in the presence of cochineal or phenolphthalein as indicator. It will be seen by referring to the analytical figures that a large amount of sodium is left after balancing the acids by the bases found. This would seem to find its readiest explanation in supposing that there was a much greater quantity of the organic acid on the plant than indicated by the equivalent of 23 cubic centimeters of twentieth normal acid, but present in the form of the sodium or other salts. By referring to the analysis (Table XVII) of the soil from which this Sample I of *Distichlis spicata* was taken, it will be seen that there was relatively a very large amount of soluble carbonates present, about 2 per cent of the soil being composed of these substances—an amount which would absolutely prohibit the growth of any ordinary plant, even though much of the salt was in the form of bicarbonate. Much of this material probably came in contact with the grass leaves, in the form of dust or otherwise, with the result that the acid decomposed the carbonates with the formation of salts of the organic acid. These same views seem to hold for Samples II and III as well, but to a lesser extent, as is shown by the quantitative measurements given.

It would appear from what could be learned in the field that this grass, in the locality from which Samples II and III were taken, often carries as much of the acid material as Sample I shows, or even more. Unfortunately for this investigation the most favorable season for securing samples had passed before Samples II and III were gathered and sent in. This subject will receive more careful attention during another field season.

ISOLATION AND IDENTIFICATION OF ACID EXUDATION.

Careful attempts were made to isolate or at least to identify this organic acid, but the attempts proved unavailing for several reasons. But very little material was at command when the investigation was taken up. The relatively large amounts of inorganic salts obtained in the water extracts could not be well separated and presented great analytical difficulties in the attempts to isolate so small a quantity of the acid as was at our disposal. Attempts to crystallize the material from solution, either as the acid itself or as a salt, proved disastrous on account of the rapid and abundant growth of fungi in the solution when evaporation of the solvent at ordinary temperatures was attempted. The solutions of the material failed to give any reactions by which it could be identified as one of the simpler and better-known organic acids. For these reasons efforts to identify it were abandoned temporarily and further work on it postponed until a time when a larger amount of the material could be obtained. It is confidently believed that the experience thus far gained will insure a successful issue to the next attempt in this direction.

HYDROSCOPIC SALT ON THE PLANT SURFACE.

The analytical results would indicate that calcium chloride as such was on the grass, but if present no signs of it were observed on the air-dried material. The samples were all thoroughly dry and not the least evidence of any deliquescent substance on the surface was apparent. It should be remembered, however, that the evidence obtained in the examination of the organic acid indicated that the calcium salt was much less soluble than the sodium or potassium salt. In all probability the greater part of the calcium in combination in the solid phase and not in the form of calcium sulphate was present as the calcium salt of the organic acid; and the greater part of the sodium which was assumed above to be in combination with the organic acid was in reality in combination with the chlorine, which the analysis as stated assumes to be combined with calcium.

On the other hand, it has been noticed that this grass when growing in the field is frequently covered with a moist, sticky substance, which there is reason to believe is caused by moisture absorbed from the air by the salts, but only in sufficient quantity to partially dissolve them, making a paste or gummy mixture. So that it is not so improbable that calcium chloride is sometimes formed and is to be found as such on the living plant.

SELECTIVE ABSORPTION OF SOIL CONSTITUENTS.

Another point brought out very strikingly by an examination of the analyses is the relatively large amounts of both calcium and potassium found in the leachings from the plants, when the proportion of these elements in the water-soluble portion of the soil is considered. These facts might possibly find an explanation in part in the lesser solubility of the calcium and potassium salts of the organic acid and the accumulation of such salts formed by contact of dust from the soil with the acid. But such reasoning does not afford an explanation of the enormously increased ratio between the chlor ions and the sulph ions found in the plant leachings as compared with the ratio of these substances in the soil. The relative absorptive powers of the plant for these various constituents are probably the controlling factors.

It would seem desirable to give earnest attention to this subject with plants grown under careful supervision in the field or laboratory, as the evidence here presented indicates that the removal or cropping of these plants for any purpose would result in taking from the soil enormous quantities of desirable plant food and the consequent raising of the proportion of undesirable elements in the soil.

FUNCTION OF THE ACID EXUDATION.

When the large amounts of soluble carbonates found in the soils upon which these plants grow are considered, and when the disastrous corrosive action of this substance is remembered, the production of the strong organic acid by the plant seems a wise protective measure of nature. The tendency of sodium carbonate to outstrip other salts in accumulating in the very top layers or crusts of a soil and there corroding the root crowns of plants has been frequently noted by all investigators of alkali problems. It would seem that this organic acid is produced by the plant in the manner most favorable to its being brought into contact with the surface sodium carbonate, partly converting this latter to the sodium salt of the acid and partly, in all probability, to sodium bicarbonate, which, there is strong reason for believing, is not itself so harmful to plant growth as the normal carbonate.[1]

PHOSPHORUS IN THE PLANT.

In the attempts to identify the organic acid on Sample I, *Distichlis spicata*, some leachings were obtained which contained a small amount of organic matter mechanically suspended, as well as some in solution. They were allowed to stand for several days in an Erlenmeyer flask, the mouth of which was covered with an inverted beaker. A rapid and voluminous growth of fungi was observed. On filtering off a small portion of the solution after it had been standing a day or two a decided though small amount of phosphoric acid was shown to be present. No trace of this substance was found in freshly prepared leachings of the plant. It would seem probable that it was formed as a result of the action of organisms either upon dissolved organic matter in the leachings or perhaps upon the organic matter mechanically suspended in the solution. From lack of material it was not possible to determine the amount of phosphorus in the plant, but the qualitative observations cited would indicate that it was present in considerable amount. It should be observed that it was a constituent of the readily water-soluble portion of the soil from which the plant was taken in very small amounts, if, indeed, it were present at all. Attempts to detect it by the phosphomolybdate method failed to show a trace. The remarkable ability of this plant to take from the soil solutions the mineral constituents it needed, in the presence of the enormous excess of other readily soluble substances, is brought out very strikingly in this connection.

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[1] The especially pernicious effect on plants of carbonate of sodium is in all probability due to the fact that this salt readily hydrolizes in water with the formation of considerable amounts of sodium hydroxide, and it is this latter substance which is in reality responsible for its great destructive power. Sodium bicarbonate or hydrogen carbonate, $Na\text{-}HCO_3$, might be expected to hydrolize to some extent also, being composed of a strong base in combination with a weak acid; this would be equivalent to a partial inversion to the normal carbonate. But in the presence of so much carbon dioxide as is present in soils this inversion to the normal carbonate would be greatly retarded or altogether prevented. The normal dissociation of the hydrogen carbonate would then be very small indeed and any chemical activity of the compound depending on the formation of ions would be correspondingly small.

For the reasons here presented it would seem that this plant is worthy of the serious consideration of the botanist and physiologist, and is undoubtedly of very great economic importance.

ASH ANALYSES.

Ash analyses of all the plants considered in this paper were made, in the hope that some conclusions might be drawn as to the inorganic materials in the plants themselves, and as to how much, relatively, was capable of being removed by leaching. These analyses will not, however, be presented, for it is obvious that they have no value whatever for the purposes here indicated. The mixture of salts on the plants was so large in amount, and fused at so low a temperature, that it quickly coated the organic matter, so that it was necessary to heat to a very high temperature and thoroughly stir the mixture to obtain anything like a thorough combustion of the organic material. This resulted in a very great loss of the salts by volatilization, sodium chloride and potassium chloride being especially important in this connection. Further, the burning of either sulphates or chlorides of the alkalies with organic materials necessarily means the more or less complete volatilization of the sulphur and chlorine, respectively, and the formation of the corresponding alkali carbonates, a point often overlooked in the consideration of ash analyses. As a consequence of these factors, the results obtained would certainly be misleading. It would appear, from the analyses of the ashes of the plants we are considering, that much more of these soluble mineral constituents can be leached from the plants than the plants ever contained, which is an obvious absurdity. For this reason it does not seem worth while to give these ash analyses any further consideration.

SUAEDA INTERMEDIA AND ATRIPLEX BRACTEOSA.

TABLE XVIII.—*Suaeda intermedia.*

	Sample IV—Stems.		Sample V—Leaves.	
Grams of substance	7.61		14.35	
Cubic centimeters of leachings	750		750	
Percentage (mineral matter) leached out	14.73		23.80	
Cubic centimeters N/20 acid, equivalent to 1 gram substance	.84		2.67	
	Percentage distribution.	Percentage in air-dried substance.	Percentage distribution.	Percentage in air-dried substance.
Ca	0.48	0.071	0.15	0.036
Mg	.75	.111	.72	.170
Na	42.36	6.239	56.18	13.375
K	7.20	1.060	4.52	1.075
SO_4	1.43	.211	.87	.206
Cl	47.78	7.038	37.56	8.938
	100.00	14.730	100.00	23.800
$CaSO_4$	1.62	.239	.51	.121
$CaCl_2$	.00	.000	.00	.000
$MgCl_2$	2.66	.392	2.35	.559
$MgSO_4$	.35	.057	.64	.152
KCl	13.71	2.015	8.61	2.049
NaCl	64.84	9.551	52.33	12.456
Na	16.82	2.476	35.56	8.463
	100.00	14.730	100.00	23.800

TABLE XIX.—*Atriplex bracteosa.*

	Sample VI—Stems.		Sample VII—Leaves.	
Grams of substance	21.49		17.79	
Cubic centimeters of leachings	750		750	
Percentage (mineral matter) leached out	4.48		10.24	
Cubic centimeters N/20 acid, equivalent to 1 gram substance	1.19		3.61	
	Percentage distribution.	Percentage in air-dried substance.	Percentage distribution.	Percentage in air-dried substance.
Ca	2.32	0.104	0.39	0.040
Mg	2.05	.092	3.36	.344
Na	37.79	1.693	41.30	4.229
K	7.90	.354	5.39	.552
SO_4	4.10	.184	6.60	.676
Cl	45.84	2.053	42.96	4.399
	100.00	4.480	100.00	10.240
$CaSO_4$	5.80	.260	1.33	.136
$CaCl_2$	1.74	.078	.00	.000
$MgCl_2$	8.03	.360	7.57	.775
$MgSO_4$	.00	.000	7.08	.725
KCl	15.03	.673	10.27	1.052
NaCl	52.18	2.338	53.56	5.485
Na	17.22	.771	20.19	2.067
	100.00	4.480	100.00	10.240

In Tables XVIII and XIX are found the data obtained from an examination of the *Suaeda intermedia* and *Atriplex bracteosa*, respectively. For the purposes of this paper they may very well be discussed together. Both analyses show the production by the plants of an organic acid or acids strong enough to decompose alkali carbonates; and that to some extent salts of this acid or acids, as well as the acids themselves, accumulate on the plants. In both plants this acid organic material is accumulated on the leaves rather than the stems, a situation which would seem more favorable for its being brought into contact with the alkali carbonates on the surface of the ground.

The accumulation of considerable amounts of potassium is again a noteworthy feature with these species. In both cases there is an apparently greater proportion of potassium in the water-soluble portions of the stems than in the leaves, when considered in relation to the other elements present; but when considered in relation with the air-dried material as a whole, the amount of potash is about the same in both leaves and stems for each of these plants.

In the case of the stems of *Atriplex bracteosa* the conventional statement of the analytical results as salts would indicate the presence of calcium chloride as such, and on the stems and leaves of both the *Suaeda intermedia* and *Atriplex bracteosa* considerable amounts of magnesium chloride are indicated. That these salts were actually present as such, however, is negatived by the fact that the air-dried samples did not in any case show the presence of any notably deliquescent substance on their respective surfaces after being dried in the oven. The conventional method of statement is again misleading. as in the case of the *Distichlis spicata*, discussed above.

SUMMARY.

From the facts which have been presented in this paper the following conclusions seem justified:[1]

1. That the plant species here considered can make a satisfactory growth on soils containing relatively large amounts of soluble carbonates.

2. That this satisfactory growth is probably due, in large measure at least, to the production and exudation by these plants of considerable amounts of soluble organic acids capable of decomposing soluble carbonates, and thus protecting the root crowns from the corrosive action of hydrolized alkalies.

3. That it appears certain that large quantities of the most valuable plant foods are removed from the soil by these plants, and that in any contemplated use of them, involving their cropping or removal from the soil, this factor merits earnest consideration.

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[1] Acknowledgment is due Mr. Atherton Seidell for assistance in making the analyses presented in this paper.

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CIRCULAR No. 3.

United States Department of Agriculture,

DIVISION OF SOILS.

THE SOILS OF THE PECOS VALLEY, NEW MEXICO.

In March, 1899, a party was sent by the Secretary of Agriculture, under the direction of the Chief of the Division of Soils, to map the soils of the irrigated districts of the Pecos Valley, New Mexico, with particular reference to the extent of and damage from "alkali" and seepage waters, and to investigate methods for the prevention of further damage and for the reclamation of lands already abandoned from these causes. Three months were spent in a thorough and detailed examination of the Carlsbad and Roswell areas, with a reconnoissance around Hagerman, N. Mex., and Barstow, Tex. The following brief review of the results of this work is presented, pending the completion of a more detailed report:

THE CLIMATE.

The climate of New Mexico is distinctly arid. The average yearly rainfall at Carlsbad is, according to a four years' record, 12 inches, with a larger proportion of rain falling during the summer and fall, from May to October, inclusive. There are occasional heavy local rains during the summer, which cause great floods in the Pecos; these floods generally commence in May while crops are yet tender, and it is upon them that the large storage reservoirs at Carlsbad are mainly dependent for the supply to the irrigation lands of that district.

The normal evaporation is said to be about 10 feet at Carlsbad from a water surface, and, as the reservoirs when full average only about 20 feet deep, it will be seen that this evaporation is an important factor both in the matter of the available water supply and its condition when long stored in the reservoir, owing to the increased salt content due to the concentration through evaporation. During the spring of 1899 the regular spring floods did not come down, the first reaching the reservoir late in June. Previous to this the evaporation in the reservoir exceeded the inflow from the Pecos River, and the condition of the water was perhaps at its worst.

THE DRAINAGE AREA.

The Pecos River drains nearly all of the southeastern third of New Mexico. Rising in the Santa Fe Range, the stream flows through the inclined rocks of the mountains as a typical mountain stream until the horizontal strata of the plains are reached. Its main tributaries all come from the western side, and they too are mountain streams rising in the White, Sacramento, and Guadalupe mountains. In time of floods these streams run large quantities of water throughout their courses, but during the greater part of the year they disappear, being absorbed in the sands and gravels of their beds soon after leaving the mountains. The numerous springs all along the west bank of the Pecos indicate that much of this water appears again as seepage water after a long journey under ground.

THE IRRIGATION SYSTEMS OF THE PECOS.

There are four large systems of irrigation on the Pecos River in New Mexico and Texas:

1. The Roswell area, deriving water from the North and South Spring rivers and the Berendo Springs.
2. The Hagerman area or Northern Canal System, the water for which is obtained from the unused, waste, and drainage waters from the Roswell area, and in time of flood from the Hondo River.
3. The Carlsbad area or Southern Canal System obtains water directly from the Pecos River by storage in two large reservoirs.
4. The Barstow area also receives water from the Pecos, but without storage.

ROSWELL AREA.

The Roswell area is confined to the land immediately around the junction of the Hondo and Pecos rivers, with narrow strips along the Berendos. The waters of the North and South springs come from great depths in the Hondo flood plain, and no doubt are a part of the water lost through seepage from the upper part of the rivers and tributaries just after they leave the mountains. The water contains on an average 75 parts of soluble matter per 100,000. Of this, only 35 parts are likely to remain in solution and accumulate within the soil, to the detriment of plant growth. The remaining 40 parts crystallize out on evaporation and concentration of the water, and are not readily soluble thereafter. The waters of the Berendo Springs, which come from the great gypsum plains, extending to the north along the Pecos, are not so good, as they contain 250 parts of soluble matter per 100,000, of which about one-half is likely to accumulate in solution upon evaporation of the water. The lands to which Berendo water is applied all lie close to the stream banks and have good underdrainage, so that no damage has resulted from the use of this saline water. There is no black alkali or sodium carbonate in the Pecos Valley, so far as observed.

THE SOILS OF THE ROSWELL AREA.

The soils of the Roswell area may be classed under three types:

1. Pecos loam, upland prairie-like soils.
2. Roswell loams, lower lands not bottoms.
3. Meadows or bottom lands.

(1) The Pecos loam is a light, sandy soil found on the upper benches away from the streams. It has been cultivated very little, except during flood in the Hondo, and has never shown trouble from alkali.

(2) The Roswell loams cover by far the greater part of the irrigation district of Roswell. They differ from the Pecos loam in being heavier; that is, they contain a higher percentage of fine material. They are subdivided into sandy loam and loam. A bed of clay underlies both soils, but that under the loam is much nearer the surface than that under the sandy loam. This clay is very impervious to water. When irrigation water is freely applied, the excess seeps down until this stratum of clay is reached, when it accumulates and rises, gradually filling the subsoil until the soil itself becomes too wet with seepage water for crops. Evaporation takes place from the wet surface, and as the soil moisture concentrates through evaporation the soluble salts accumulate at or near the surface of the ground until finally plants can no longer grow. Of the kind of alkali found at Roswell, about one-half of 1 per cent in the top foot of soil is sufficient to prevent alfalfa growing. Drainage is the one great need of these soils. The water drawn off from the subsoil would lessen the evaporation from the surface and carry out into the rivers the salt which has accumulated near the surface, besides lowering the level of the ground water.

(3) Meadows or bottom lands occur along the North and South Spring rivers and along the Hondo. The soil in all of these is formed from mud, deposited by the Hondo when in flood, mixed with the remains of tulé swamps and other water-loving vegetation. Most of the bottom lands are wet and would require drainage even in a humid climate, but situated as they are, quantities of alkali are accumulating in the surface, and only by thorough drainage and washing away of these salts can these lands now be reclaimed.

THE PROBLEMS OF THE ROSWELL DISTRICT.

To the most casual observer, the flat tract of land to the southeast of Roswell lacks underdrainage. The water table lies at an average depth of less than 5 feet below the surface. Over much of what was once the best land in the district water can now be found within 3 feet of the surface during part of the year. Such a condition of standing water is unhealthy to the plants growing on the surface and, moreover, in a country where the subsoil is charged with alkali salts it is dangerous to allow this subsoil water to collect and evaporate from the surface. The best results from cultivation can never be realized until the land is thoroughly drained. Cultivation and forage crops which shade the ground will to a large extent, prevent evaporation, but in many cases the damage has gone too far for such preventive measures to be successfully used.

THE HAGERMAN AREA OR THE NORTHERN CANAL SYSTEM.

This area comprises a narrow strip of land running south from the Roswell area along the Pecos River. The water of the Northern Canal is a mixture of the Berendos and Spring rivers, together with the waste, drainage, and seepage water from the Roswell district. The character of the Northern Canal water is therefore not the best. It carries on an average about 200 parts of soluble matter per 100,000, of which about 115 parts are resoluble after evaporation and therefore likely to accumulate in solution. Thus we see that the water introduced into the soil contains one-tenth of 1 per cent of soluble matter. Since few plants can successfully grow with their roots in contact with a solution of more than 1 per cent concentration, it requires only a concentration to one-tenth to bring the soil moisture to the maximum limit allowable. Proper precautions must be taken, therefore, to avoid excessive evaporation from the surface of the soil.

The soils at Hagerman are of corresponding types to the Roswell area, with the addition of one new type—gypsum soil, or "yeso" as it is termed by the native Mexicans. The soil is so much more typically developed in the Carlsbad area that its description will be given there.

The main problem which confronts the farmer at Hagerman is similar to that in the Roswell area—that is, the prevention of the accumulation of alkali near the surface. Over land which has adequate natural drainage very little damage has been felt from this cause. On the heavier soils and where the gypsum comes close to the surface, these lands must be underdrained. One attempt has been made to underdrain the land and this with fair success, though not as yet completed.

THE CARLSBAD AREA OR SOUTHERN CANAL SYSTEM.

The flow of the Pecos above Carlsbad sometimes becomes very small, as low as 50 to 75 cubic feet per second. At other seasons of the year great quantities of water flow. Two large storage reservoirs have been constructed on the Pecos to hold back this flood water, and from these reservoirs the water is turned into the Southern Canal as desired. The canal was originally planned as far south as the Delaware River, but has only been used to a short distance below the Black River. The average condition of this water is not good, as it contains about 300 parts of soluble matter per 100,000, of which over half are harmful salts—the condition of the water varying from 200 parts per 100,000 to 500 parts per 100,000. With 500 parts per 100,000, or one-half of 1 per cent, the solution contains one-fourth of 1 per cent of harmful salts; 1 per cent being the limit of endurance of crops. There is considerable salt already in the soil, therefore, but little evaporation is required at such time to concentrate the soil moisture beyond the limit of endurance. Furthermore, with the conditions so near this limit, vegetation is not as healthy or as thrifty as could be desired and crops are subject to disease. During the winter the water is constantly evaporating from the reservoirs, and if the inflow is small it may be concentrating. This water, in its worst condition, is applied to the young and tender plants just at the time when the water should be best. The first summer floods bring down large quantities of alkali which have accumulated on the surface of the ground of the Upper Pecos, and these floods seldom improve the water. In later floods the water is better and reaches its best condition.

THE SOILS OF THE CARLSBAD AREA.

The soils of the Carlsbad (formerly Eddy) area have been divided into four types:

1. Sand-dune soils.
2. Pecos loams.
3. Pecos conglomerate soils.
4. Gypsum soils.

(1) Along the banks of the river, filling up the tortuous bends of its course, are found large areas of sand soils drifting with the winds as dunes. These sands are composed of a very uniform grade of clean grains, rounded by attrition. When cultivated, these soils drain easily, owing to their favorable situation near the banks of the river. Quantities of salt are to be found in these soils before irrigation, though little damage has been done by this alkali, due to the ready leaching by the irrigation water.

(2) Pecos loams cover by far the largest and most important part of the Carlsbad district. They are identical in texture and physical properties with the loams described as forming the uplands at Roswell. They are formed, much in the same way as the Pecos loams at Roswell, from the sediments of an ancient lake. This loam contains a large proportion (10 to 20 per cent) of carbonate of lime, and from 1 to 2 per cent of sulphate of lime or gypsum. No accumulation of alkali was found within this area, though borings were made to a depth of 20 feet, except in the draws, where the seepage from the surrounding country, together with evaporation, have accumulated large quantities of alkali in concentrated solution. There are

two points in particular where the irrigation or leakage from canals on the upland has swamped low-lying lands—along the foot of the gravel bluff which bounds the Pecos bottoms southeast of Carlsbad, and in another draw immediately east of Otis. In both of these cases, which are rapidly being brought into the condition of alkali flats, the water has seeped out of the surrounding higher lands and swamped the draw. Evaporation has, in the course of several years, covered part of these areas with a crust of salt. Attempts are now being made to reclaim a portion of one of these flats by open drains. Owing to the soft ground, open drains are a constant source of trouble and expense. Tile drains will be found much better, though the initial cost may be higher.

(3) The Pecos conglomerate soils are formed from the weathering of the local beds of conglomerate or, in some cases, of the unconsolidated gravel. All of these soils are classed as gravelly, and at present are not used.

(4) The gypsum loam soil occupies a large irregular area between Cass draw and Black River, with another large area south of Black River and Malaga. The pure gypsum is generally covered with a thin layer of loam, varying from a fraction of an inch to 3 feet. The gypsum, when dry, is hard and compact, but when wet it absorbs water as readily as a loaf of sugar, and breaks down into a soft mass which is very pervious to water and possesses great capillary powers. The height and rapidity with which water rises in gypsum soils is very remarkable when compared with others. In a field wet spots were noticed where, on boring, no standing water was found within 6 feet of the surface. The great capillary power keeps the surface perceptibly moist all the time, and, when placed under the hot sun of southern New Mexico, it can be seen that the evaporation will soon concentrate the soil solutions to such a degree that few plants may live. It is undoubtedly this physical property, and not the chemical nature of the gypsum itself, which renders its cultivation so unprofitable, though there are some plants to which the presence of so much lime is obnoxious.

Drainage can be recommended for gypsum soils, but since the capillary powers are so great and the evaporation from the soil surface so rapid it is a question whether reclamation of these gypsum lands by costly drainage is a profitable or safe investment at present. There are so many serious difficulties in the way of practical cultivation of gypsum lands that from our present knowledge this attempted reclamation is to be discouraged.

THE PROBLEMS OF THE CARLSBAD AREA.

With the exception of the sand dune soils bordering immediately on the Pecos River, wet at times of high water, and in a few cases the gypsum also, the soils of the Carlsbad area were originally free from noticeable quantities of alkali. The sources of the present accumulations of alkali are all directly traceable to the irrigation water. All recommendations for the prevention of damage by alkali must, therefore, point primarily to a change in the method of handling the present supply of water or of obtaining a better supply.

DRAINAGE.

Drainage is recommended as of most general application in the Carlsbad district. Tile drains should be laid for soils in which the water table rises above 3 feet. When the soil is open and dry, and where seepage water has not accumulated, cultivation or growth of alfalfa should be used to prevent surface evaporation and the consequent concentration of the soil moisture. Salt determinations have been made in cultivated and uncultivated ground, side by side, in which the uncultivated land showed three times as much alkali as the cultivated. Where salt has already accumulated, drains must be laid and the salt washed out by flooding. Surface washing without drainage is of little avail, for the first film of water dissolves the salt and sinks into the ground to appear again when evaporation commences. If, however, this water can pass through the soil and into drains, the salt is carried away, and no further damage from it need be feared.

THE BARSTOW AREA.

The Barstow area lies in an old lake basin, and the soils are derived from the old lake sediments. The soils all contain alkali in their lower depths, and in many cases are underlaid by gypsum.

The Pecos water, where taken out, contained in June, 1899, about 390 parts of soluble matter per 100,000, while the Pecos opposite Pecos City contained 525 parts. This concentration of the water, which must be near its average condition, is so near the limit for plant growth that only where the most favorable conditions of soil and drainage are found can agriculture be termed successful.

THOS. H. MEANS,
FRANK D. GARDNER,
Assistants.

Approved:
JAMES WILSON,
Secretary of Agriculture.

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CIRCULAR No. 4. S. 28.

United States Department of Agriculture,

DIVISION OF SOILS.

Cooperating with the Utah Experiment Station.

THE SOILS OF SALT LAKE VALLEY, UTAH.

OBJECT OF RECENT SURVEY.

In July, 1899, the Division of Soils, in cooperation with the Utah Agricultural Experiment Station, undertook a survey of that portion of Salt Lake County lying immediately west of the Jordan River and extending to the Great Salt Lake and the Oquirrh Mountains on the west, the object being to map the soils with particular reference to the extent of, and damage from, alkali and seepage waters.

EARLY IRRIGATION WORK.

Irrigation began here a half century ago and, for the most part, has been confined to that portion of the area nearest the river Jordan and south of the Twelfth street road. This irrigated portion consists of a number of benches, one above another, extending in a general direction parallel with the river and comprising an area about two miles wide and sixteen miles long, extending south from the Twelfth street road and bordering on the river—together with another portion not quite so wide, which turns westward—following the contour of the foothills and extending nearly to the point of the Oquirrh Mountains. The land slopes toward the river, or to the north, at the rate of fifty to one hundred feet per mile.

The earliest irrigation was successfully practiced on the Jordan meadows or bottom land, but later, when canals were constructed and irrigation began on the benches, the bottom land became so wet that the greater part of it has been abandoned and now lies as pasture or waste land.

RECENT IRRIGATION IMPROVEMENTS.

The latest, largest, and uppermost of the canals running over these bench lands is the Utah and Salt Lake, which is about two hundred feet above the level of most of the river bottoms and the low lands to the north. At its furthermost extremity this canal is about eleven miles west of the river. In the last six or seven miles of its course it passes over soil that is underlaid quite close to the surface by gravel, which is in turn underlaid at a considerable depth by an impervious layer of clay. The clay outcrops from one to two miles north of the canal on considerably lower land. As a result of this structure and the considerable irrigation on the upper lands, a large area has here become so damaged by seepage water and alkali that it has been abandoned.

Both the South and North Jordan canals, which lie between the Utah and Salt Lake canal and the river, are responsible for much similar damage, especially at their outer extremities. Parallel with the Twelfth street road and about one mile south of it is a strip of land extending from the river about ten miles west, varying from one-half to one and one-half miles in width, all of which is more or less damaged by seepage water and alkali. Indeed, the damage has gone so far that a chain of lakes has been formed in this area, presenting a water surface of a thousand or more acres. This has all resulted from the seepage and surplus waters from the irrigated districts above. The total area which has been successfully irrigated is about fifty square miles, of which about ten square miles have been ruined by seepage water and alkali.

Of the larger, much lower, and level area, mostly north of the Twelfth street road and adjacent to Salt Lake City, extending from the river Jordan to Great Salt Lake and comprising about one hundred and twenty-five square miles, none has been successfully farmed, with the exception of a narrow belt along the river, although many attempts have been made and much money expended in this endeavor. About eleven years ago this area was the seat of an extensive boom—suburban townsites were laid out, streets graded, canals constructed, and artesian wells sunk; railroads were built and operated, parks were laid out and trees planted, buildings were erected for homes and stores, and, in the aggregate, hundreds of thousands of dollars were expended, for which no returns have ever been realized, excepting, perhaps, by the shrewd speculator.

The first-year crops that were cultivated gave fair returns; the second year failure was general, and the third year absolute. At present there are in this area many deserted houses and much unused land, which bears evidence of having once been cultivated. The cause of this failure and of the damage wrought by irrigation have, perhaps, never been fully understood by any one.

Four months were spent in a thorough and detailed examination of this area, and the large amount of data thus collected has given a far better understanding of the existing conditions than has ever before been realized. It is hoped that this knowledge will suggest the lines to be followed in order to overcome the difficulties that will be encountered in future attempts to farm this land.

The results of this work are embodied in the following statements, pending the completion of a detailed report:

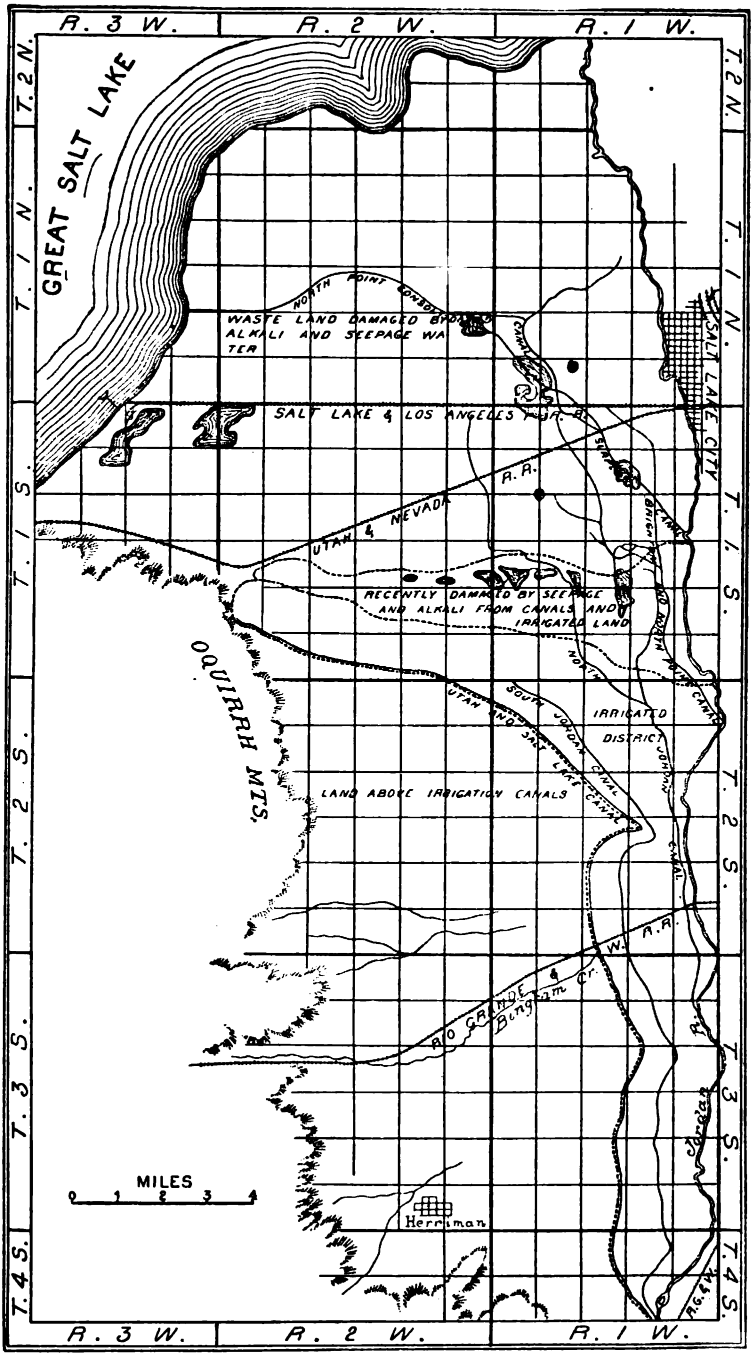

FIG. 1.—Map of a portion of Salt Lake Valley, Utah.

CLIMATE.

Rainfall records previous to the establishment of the Government weather service at Salt Lake City, show an annual variation of from 10 to 29.5 inches. At Salt Lake City the mean annual rainfall, according to the record of the past twenty-five years of the U. S. Weather Bureau, is 16 inches, with a minimum of 10.3 and maximum of 23.6 inches. Of this annual rainfall, less than three inches fall during the four warmest months of the year—June, July, August, and September. These four driest and warmest months, having a total mean rainfall of less than three inches and a mean temperature of 70.4° F., are accompanied by a low, relative humidity—conditions favoring excessive evaporation.

It is estimated that the annual evaporation from a free water surface in this locality is eight feet. Calculations from data of one of the salt companies show the evaporation from their ponds to be thirty-seven inches for the four months of June to September. It must be borne in mind, however, that this is from a saturated brine, and that the vapor tension, and consequently the evaporation, is much lessened by the presence of large quantities of salt.

Since the greater part of vegetable growth is made during these four months, these data show how important and necessary is irrigation for the production of crops. Indeed, no farming is carried on without irrigation except in the case of wheat, which makes most of its growth prior to June, and from which small yields is the rule rather than the exception.

WATER SUPPLY.

The Jordan River, from which all of the irrigation water used on the above area is taken, is the main channel through which the waters of a large number of streams extending well back into the mountains east and south, as well as the waters of Utah Lake and its inflowing streams, make their way to the Great Salt Lake. The annual precipitation in the mountains exceeds that in the valleys and is largely of snow, which lingers on the highest mountains during the greater part of the summer. The melting snow and the numerous mountain springs make the irrigation water supply constant, plentiful, and of good quality. The Utah and Salt Lake and the South Jordon canals get their water supply from the Jordan River, near the Jordan Narrows, and it is representative of the water of Utah Lake, which was found to contain eighty-nine parts of soluble matter in one hundred thousand parts of water. Of this only about fifty parts are likely to remain in solution and accumulate in the soil to the detriment of plants.

A few miles below the head of the South Jordan canal the seepage waters from the adjacent irrigated districts begin to return to the Jordan River. This seepage water, together with the unused portion of waters of the mountain streams to the east—Big and the Little Cotton Woods, Mill Creek, and City Creek, make the composition of the river water exceedingly variable during the remainder of its course. The seepage waters, with their high salt content, tend to make the water poor, while the mountain streams dilute and improve its quality.

The mean salt content of the North Jordan canal is about one hundred and seventy parts in one hundred thousand, or, practically, twice as much as that of the South Jordan. Below this the water of the Jordan, because of the entrance of mountain streams, improves; and we find the mean salt content of the Surplus and the North Point Consolidated canals to be about one hundred and thirty-five parts in one hundred thousand. About two hundred and fifty parts to one hundred thousand is the limit of safety.

In large irrigation canals water may flow for many miles and deteriorate very little in quality, while in small ditches the deterioration may become apparent through the evaporation of water and collection of salts from the banks of the ditch.

The aggregate capacity of the irrigation canals on this area is about six hundred cubic feet per second, but very much less than this amount of water is required or used on the twenty-five thousand acres that are now under irrigation. During the entire summer of 1899, large volumes of water were constantly passing the intake of the Surplus canal, and there is apparently enough water going to waste to irrigate all of the better lands west of Salt Lake City, between the river and the Lake.

SOILS.

The soils of this area have been classed under eight heads—

(1) Jordan sands.
(2) Jordan sandy loams.
(3) Jordan loams.
(4) Jordan clay and clay loams.
(5) Jordan meadows.
(6) Bingham gravelly loams.
(7) Bingham stony lands.
(8) Salt Lake sand (oolitic sand dunes).

1. The Jordan sands comprise a small area, usually a narrow belt along the bluffs bordering on the Jordan meadows or river bottom soils. The sand is generally fine-grained and continuous to six or more feet in depth, though occasionally underlaid at a less depth by loam or clay.

2. The Jordan sandy loam is the most important soil, both in point of area and of quality. It is a light sandy loam, ranging from one to several feet in depth and varying somewhat in its underlying strata. The most usual profile is two feet of sandy loam, one and one-half feet of loam and one foot of sand, all of which is underlaid by clay to a considerable depth.

3. The next most important type of soil is the Jordan loam, which is somewhat heavier than the sandy loam and, like the above, varies much in depth and underlying strata. Its most usual form is three feet of loam underlaid by clay, which frequently contains veins or pockets of fine sand.

4. An unimportant type of soil, agriculturally, at present is that of the clay and clay loams, which are low, level, wet areas lying near the lake (usually called "playas") and extending back into the better lands like fingers of a bay. It is all very salty and usually void of any vegetation. The clay is quite continuous to a considerable depth, although frequently inlaid with veins, or pockets, of very fine sand. The fingers, which extend far back like wide, irregular canals from four to eight feet deep, would furnish efficient drainage outlets for the adjacent good lands.

5. The Jordan meadows comprise a narrow belt, from a few rods to a half mile in width, which borders on the river Jordan. The soil being formed from the sediment of the river, is black and contains much organic material. It varies in depth from one to several feet, and in texture from sandy loam to clay. The most common form, however, is two feet of loam, two feet of clay, and one foot of coarse sand, all of which is underlaid by gravel. Where the gravel is not present, the soils are now usually very wet, and but little used except for pasture. The wetness is caused by seepage from canals and irrigated lands above. If drained, they would be fertile and productive.

6. Lying for the greater part above the irrigation canals is a large area of good land, which contains gravel within three feet or less of the surface. The gravel frequently comes to the surface, but it is here too small to materially interfere with cultivation. Below the surface the gravel becomes larger, and at several feet in depth may approach the size of bowlders. This area, considerable of which is dry-farmed to wheat, is called the Bingham gravelly loam.

7. The Bingham stony loam comprises a small and unimportant area near the foothills, which is too stony to be cultivated.

8. The Salt Lake sands (oolitic sands) are chiefly carbonate of lime, spherical in form and about the size of No. 10 shot. This sand is probably formed by the throwing down of carbonate of lime in the water of the lake, which is washed to the shore where the wind still

transports it further inland. It constitutes for the most part dunes along the lake shore and is of no importance agriculturally.

As is frequently the case with alluvial and sedimentary soils, the soils of Salt Lake Valley, especially those north of Twelfth street road, are heterogeneous and much mixed up, perhaps more so than is usual. They were probably first formed in the bed of the old lake, Bonneville, by sedimentation, and after its subsidence further modified by the vacillating shore of the more modern Great Salt Lake and the inflowing streams from the adjacent mountains.

ALKALI.

The salts, as they occur in the soil, vary greatly in quantity. In the best agricultural lands the amount present is frequently less than .05 of 1 per cent, while in the salt flats there may be as high as ten per cent, exclusive of the crust that frequently forms in much greater concentration. Sodium chloride, or the common salt of commerce, forms from fifty to ninety-seven per cent of the total salts present. Besides this, there are considerable quantities of the sulphates of soda, lime, and magnesia, chlorides of lime and magnesia, and also carbonate of soda, or true black alkali. The black alkali is nearly always present in amounts varying from a trace up to several per cent in small local spots. There is, in the aggregate, a large area in which it occurs in sufficient quantity (.1 per cent) to be fatal to crops.

It seems quite probable that this accumulation of salt came chiefly from two sources—i. e., from the higher lands to the south and from the waters of Great Salt Lake. It is most likely that the lake is the source of the greater portion of them, for when it was from thirty to fifty feet higher than now, it would have submerged nearly all the area under consideration, and must have also contained much salt in solution. Upon the subsidence of the water the soil would, of course, be left heavily impregnated with salts. Besides, within the memory of the present inhabitants, the lake has again submerged a considerable part of this area, and, according to reliable records, the lake in 1868 was twelve feet above its present level, and at this height must have covered at least fifty square miles of what is now mapped as dry land. The water at that time carried, approximately, 13.5 per cent of salt, and land submerged for a considerable length of time in such a solution would certainly be left very salty when the water subsided. More land than that merely covered by the lake must have been affected by it. The water-table of the low land adjacent to the shore must have risen to an elevation equal to or exceeding the level of the lake water, while in time of storms the waves may have rolled inland for considerable distances. It is fair to assume that all land now having an elevation not to exceed twenty feet above the present lake level, was more or less affected by its waters at that time.

Practically all of the comparatively level area north of Twelfth street road, when considered to a depth of five feet, is salty land. There are considerable portions of it, however, in which the salt content of the first, and sometimes the second, foot is so small as to indicate that it could be safely used for agricultural crops. Below the second foot the salt increases very rapidly and far exceeds the limit for most plants. This increase continues as we descend until within one foot of the water-table, where the maximum is reached. Below the water-table the saltiness is quite constant for a number of feet, diminishing slightly as we descend. On this type of land, usually sandy loam or loam, the water-table is seldom more than six or seven feet below the surface, though it is occasionally as much as ten feet. It is on this land that numerous, unsuccessful attempts have been made at farming during recent years, and the failure has undoubtedly been due to the following causes:

In its natural state this land is, for the most part, covered with a growth of greasewood. The salts having been carried from the surface into the deeper soil by the natural precipitation, were undoubtedly largely prevented from rising again by this deep-rooted plant absorbing the soil moisture at its roots, thus preventing much surface evaporation. When this land was broken up for cultivation, the soil moisture instead of being thus absorbed in the lower soil, rose into the upper, bringing the salts with it, to the detriment of the shallow-rooted agricultural plants. The land, being level and underlaid with a strata having a fairly close texture, had naturally poor drainage. The water-table was rarely more than seven feet below the surface and frequently of less depth, and upon the application of irrigation water it gradually rose. When the water-table was within three feet of the surface much evaporation naturally occurred from the resulting moist soil surface. In this condition the salts from the lower soil rapidly rose to the surface and were left by evaporation as incrustations, or were moved up and down in the surface soil with the movement of the rain and irrigation water, in such concentration as to prevent the growth of most plants.

Under these conditions farming was a failure, and at present few attempts are being made to do anything with this kind of land. There are a few places of limited extent along the border of draws, or on ridges, where the natural drainage is sufficiently good for irrigation farming to be carried on. With good judgment as to irrigation and cultivation, some of these places are producing alfalfa and garden products successfully. These places, while insignificant in themselves, are very suggestive as to the means by which all of this area might be reclaimed.

As an illustration of the effect that elevating the water-table has upon the accumulation of salt in the surface soil, take, for example, the playas and all low ground where the water-table is within three feet or less of the surface and we find that the surface portion of the soil is almost invariably the most salty, and is very often covered by a salt crust.

The irrigated land south of the Twelfth street road has, for the most part, good, natural drainage, and is generally quite free from salts. There are a few areas, however, including the greater part of the Jordan meadows, which form an exception. Here, owing to poor, natural drainage, seepage water has accumulated from the irrigation of lands above, and the injury is more from water than from salt. In most cases, however, the seepage water is accompanied by an accumulation of salts immediately at or near the surface. The source of these salts is usually from the seepage water accompanied, perhaps, by an upward movement of the original salts of the soil. This accumulation at the surface is brought about by the excessive evaporation from the wet surface of the soil.

THE PROBLEMS OF THE AREA.

The areas damaged by seepage and alkali would be less extensive if there had been a more judicious management of the irrigation water. Because of an abundance of water, it has at times been used in excessive amounts. and, furthermore, waste or surplus water is too often allowed to run on to vacant lands when the canal gates should be closed. Each irrigation should be of sufficient quantity to wet the ground to a considerable depth and yet cause little or no drainage. The soil moisture should be conserved by the best means of cultivation and cropping, thus making the intervals between irrigations as long as possible. It is true that lands are sometimes of such a character that large areas cannot be irrigated without causing seepage water to escape. Where damage is already done, the land can sometimes be redeemed by warding off the seepage by means of a drain along the upper side of the affected area. It will, however, usually require a system of drains to affect this, and, if salts have accumulated to a considerable extent, thorough drainage is the only recourse.

DRAINAGE.

Of the one hundred and twenty-five square miles lying mostly north of Twelfth street road and between Salt Lake City and the lake, ninety square miles, or about fifty-eight thousand acres, are capable of reclamation. For this portion, tile drainage is recommended as of general application. There is a constant and plentiful water supply of good quality for irrigation, which may be obtained without the construction of costly dams and storage reservoirs so frequently required in many of the irrigated districts.

The soil is of good texture and the land lies so as to be easily irrigated. Furthermore, its proximity to the metropolis of the State makes it more valuable than if it were far removed from a commercial center. The excess of salts is the principal obstacle in the way of this area being profitably farmed. The problem, therefore, resolves itself into how to get rid of the salts. There is no antidote for them, except in the case of sodium carbonate or black alkali. For this, gypsum is a corrective. Unfortunately, where there is an excess of sodium carbonate there is also an excess of the other salts, and to convert the black alkali into white alkali by the use of gypsum would still leave an excess of salts in the soil. There is only one feasible way of getting rid of these salts, and that is by providing a thorough system of under drainage and washing them out by flooding.

Surface washing without drainage is of little avail, for the first application of water dissolves the salts and they pass into the ground only to return to the surface when evaporation commences. If tile drains are present the dissolved salts will pass through them and thus be carried away, so that further damage from them need not be feared. The question that must be answered is, Will it pay to reclaim these lands? This will be determined by the present value of the land, the cost of reclaiming, and the value of the land after being reclaimed.

An estimated value for the land of fifteen dollars per acre, while much less than some of it is being held for, is more than its real value, which, in its present condition, is merely nominal. Good farming land on the east side of the Jordan River, having a water right and free from alkali, can easily be sold at from seventy-five to one hundred dollars per acre. There is no reason why the alkali land west of the river should not be pretty nearly as valuable when reclaimed and a good water right secured.

The cost of drainage will vary somewhat, according to the character of the soil and the price of labor and material. The Jordan sandy loams and Jordan loams will be most easily reclaimed because of their lighter texture. The distance between drains will be determined by the texture of the soil. The more open the texture and structure of the soil, the more readily will water pass through it and the greater can be the distance between drains. The depth should be three feet or more. The rate of removing the salts will depend principally upon the rate of movement of the soil waters.

For drains three feet deep and at a uniform distance of one hundred feet apart, the cost should not exceed fifteen dollars per acre. While the proper distance between drains can be accurately ascertained only by experiment, yet it is our judgment that a distance of one hundred feet between drains could frequently be increased and would seldom require to be decreased. In addition to the above, there would be the cost of constructing outlets to conduct the water to the lake or river. For this area, the expense would be comparatively small, on account of the long draws that now extend back into the land like irrigation canals. These may require deepening and supplementing in places.

In order to be carried out in the most economical way, drainage should be made a community affair, and the systems should be planned with reference to a general scheme, especially where a large number of land owners are involved.

FRANK D. GARDNER,
Assistant, *Division of Soils.*

JOHN STEWART,
Assistant Chemist,
Utah Experiment Station.

The publication of this circular, approved by Prof. Milton Whitney, Chief of the Division of Soils, and Prof. Luther Foster, Director of the Utah Experiment Station, is hereby authorized.

JAMES WILSON, *Secretary.*

CIRCULAR No. 8.—Revised edition, October, 1903. (S. 45.)

United States Department of Agriculture,

BUREAU OF SOILS.

U. S. DEPARTMENT OF AGRICULTURE,
Washington, D. C., August 3, 1901.

SIR:

About six months ago Dr. L. O. Howard, the Entomologist of this Department, requested the cooperation of the Division of Soils in some practical demonstrations of the feasibility of getting rid of the mosquito pest in certain tidal swamps of the Atlantic Coast. Dr. Howard had been advising about the extermination of mosquitoes in an area around Oyster Bay, L. I., and requested us to investigate the character of the soils of the tide marshes and the possibilities of reclaiming them for agricultural purposes. Mr. Thos. H. Means, of the Division of Soils, was assigned to this work, and made a preliminary examination, the results of which are briefly described in this circular.

It is believed that the information contained herein is sufficiently suggestive of the possibilities of further work to warrant publication at this time, and that the seriousness of this problem along the whole coast is certain to demand attention in the future. The presence of the mosquitoes has been an important contributing cause to the abandonment of lands and the depreciation of property values along the Atlantic, Gulf, and Pacific coasts.

Respectfully,

MILTON WHITNEY,
Chief of Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

RECLAMATION OF SALT MARSH LANDS.

INTRODUCTION.

Tidal swamps and salt marshes are a prominent feature in nearly all States which border the Atlantic or Pacific ocean. A few years ago much was heard about their reclamation. Their value as farming lands was clearly shown, and the fact that they were a serious menace to the health of people in the vicinity was dwelt upon. About this time several Government reports were issued. Notable among these reports were "Sea Coast Marshes of the United States," by N. S. Shaler, published in the Sixth Annual Report of the U. S. Geological Survey; "Tidal Marshes of the United States," by D. M. Nesbit, published as Special Report No. 7 of the U. S. Department of Agriculture, and numerous notes and reports in the publications of the New Jersey Geological Survey. Some of these reports are out of print and all are now difficult to obtain.

Within the last ten years investigations have been pursued by scientists in Europe and this country which have conclusively proved that certain species of mosquitoes are the most common, if not the only, means of conveying malarial germs and of introducing those germs into the human system. More recently mosquitoes have been found to be the cause, and so far the only proved cause, of the infection of yellow fever. Marshes and stagnant pools of water are the principal breeding places of mosquitoes, and to remove the pests such places should be drained and the lands reclaimed for agricultural purposes. In Italy the mosquito pest has been the cause of the abandonment of vast areas of land. The salt marshes do not seem to offer the condition necessary for the breeding of the few species of malaria mosquitoes existing in this country, but they are breeding places for vast numbers of mosquitoes of other species which annoy the residents and stock along much of the coast line and in certain places impair the property valuation.

These recent discoveries of the cause of the infection from malaria and yellow fever have resulted in a renewed interest in the means of exterminating mosquitoes and incidentally in the drying out of marshes and swamps. The writings of Dr. L. O. Howard, Entomologist of this Department, on mosquitoes have aroused the interest of the inhabitants of mosquito and malaria infested localities in the subject of swamp reclamation; and this Bureau is in frequent receipt of letters inquiring about the agricultural value of the marsh lands and methods for their reclamation. A great many people seem willing to undertake the drainage of these marshes and tidal meadows if it can be shown to them that there will result a pecuniary profit. Therefore, to determine the agricultural value of these soils a trip was made to Oyster Bay, Long Island, where reclamation work was in progress. Samples of the soil and subsoil of the eel-grass mud were collected and subjected to laboratory examination. No elaborate study of the subject is possible at this time, so a simple statement of the conditions existing there is all that can be made.

The conditions are sufficiently typical of coast marshes all along the Atlantic coast to warrant the application to other localities of any lessons learned. The opinions of several earlier writers on the subject have been quoted, and it is to be hoped the value of marsh lands has been brought out clearly enough to direct more serious attention to their reclamation. Shaler[1] says:

> The great advantage of the northern marsh areas is found in the fact that they are generally near the larger centers of population of the country, where they will have a high value as market-garden soils or fields for the raising of hay. When brought into their best state such areas will, measured by the price set upon other lands in the same neighborhood, have a value of not less than $200 an acre. As the total reclaimable area between New York and Portland (Maine)

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[1] Sea Coast Swamps of the Eastern United States, U. S. Geological Survey, 6th Ann. Rep., p. 380.

probably exceeds 200,000 acres, the money value of their best state will amount to at least $40,000,000. The cost of reclaiming these lands and reducing them to cultivation should not exceed the fifth of this sum.

In European countries salt marshes are regarded as the most fertile of lands. Large areas in Holland, Denmark, Germany, and Belgium have been cultivated for many years. In England the Fens to the extent of probably more than 1,000,000 acres have been diked and ditched and are now in a "state of matchless fertility."

The reclamation of tidal lands to be successful at a minimum expense should be managed by a man of experience in such matters. The question of how to build dikes, the cheapest and most efficient method of drainage to be employed, and the subsequent management of the soil to bring it into a state of fertility at the earliest possible moment, are all problems which require experience and judgment if the work is to be a success. Unfortunately, in America there are no trained agricultural engineers, nor is there an institution of learning which claims to train expert agricultural engineers. The best person, then, to plan and manage the reclamation is a civil engineer who has had experience in some related work. Men of experience have a habit of charging well for their services, but the money spent in fees to the right man is well invested. Diking and ditching done by inexperienced or careless persons will require more in repairs each year than would have been necessary to insure proper supervision in the first instance.

Shaler (Loc. cit., p. 377) very aptly says:

> Where efforts have been made to exclude the sea and actually till the land they have sometimes been unsuccessful, owing to the failure of those who carried on the trial to see the true condition of the work. It is very much to be regretted that these experiments are not directed by some one trained in the work as it is effected on the northern shores of Europe, who could have brought to the task the accumulated experience of centuries; if this had been done it is tolerably certain that the process of turning these American marshes to agriculture would now be well advanced.

RECLAMATION OF TIDAL MARSHES.

The first step in the reclamation of tidal marshes is the exclusion of the sea. Ordinarily the marshes are covered by sea water only at high tide—some of them at every high tide and others only at the highest or spring tides. Salt water is harmful to most all plants and its presence in the soil will effectively prevent the growth of ordinary farm crops. To exclude the sea a dike or embankment must be built at least 2 feet higher than the highest tide. The method of building such dikes must, of course, depend upon the locality, the exposure to wave action, and the kind of dike-building material at hand. The material in most common use is the sod and soil from the marsh itself. It is cut from the swamp just inside of the position to be occupied by the dike and the excavation acts as a drainage canal. The outer slopes of the dike should have a grade of at least 1½ horizontal to 1 vertical and should be shielded from wave cutting by being well sodded with the marsh sod. On exposed shores, where the wave action may be great, special precaution should be taken to prevent washing by waves. The precaution may take the form of masonry work or stone facing in the more substantial dikes, or it may be a simple brush fence held in place by stakes driven in the ground. Various expedients of this nature, both cheap and effective, will suggest themselves to the engineer.

The ditch on the inside of the dike should be designed for drainage. This ditch is usually situated along the lowest portion of the marsh and is well placed to receive the lateral drains from the higher portions, and, being at one end of the field, it is of little obstruction in the way of cultivation. The dimensions of this ditch will be governed by the amount of material required to construct the dike, if the dike material is all taken from the ditch. A mistake is often made by digging the ditch too wide. Consideration must also be given to the amount of water emptying into the drains from the entire watershed and to be removed in a given time. It is very seldom necessary to remove more than one-half of an inch in depth of water in any twenty-four hours, and if the ditches are planned to carry this much water the drainage is good. Under certain conditions the open ditches should have a capacity of as much as one inch in depth over the entire watershed tributary to the ditch. The outlet of the main drains should be through the dike by means of an automatic sluice or tidal gate. Ample room for storage of the drainage water which may accumulate during high tide should be allowed and the sluice gates should be of at least twice the capacity of the main ditch, so that the entire drainage during high tide may be removed during the interval of low tide.

On exposed coasts, where the maintenance of an outlet would be difficult or when the drainage is desired at a level lower than the lowest tide, some other means of getting the water over the dike must be planned. Windmills have been favored in European countries and have been used in a small way in America. Various forms of pumps of cheap construction and of great efficiency are now in the market, and when driven by steam or gas engines are probably the cheapest form of water-lifting machinery and are not dependent upon the vagaries of the wind. Such a lifting plant need not be run all of the time, if storage of the drainage water can be allowed. The conditions are exceptional where the pumping is necessary during the entire growing season.

UNDERDRAINAGE.

Tile drains are the most effective means of removing water from land and in the course of time will prove the cheapest. Farmers' Bulletin

No. 40 of this Department treats of farm drainage, and more detailed information can be obtained from various publications on the subject.

In the ordinary condition in which tidal marshes are found it is unwise to place tile until the land has had opportunity to drain and settle; otherwise in the settling the tile will be displaced and rendered of little use. For this reason the ditches for the tile drains should be dug and allowed to work as open drains until the excess of water from the soil and the settling which accompanies the drainage is over. In cases of very peaty swamps this sinking is great and continues for a long time. More permanent open drains are then essential, but they should be maintained as open drains no longer than necessary.

The distances between the drains will vary with the soil. In light porous soils a distance of 300 feet is allowable, while in stiff and tight clays drains 30 feet apart are sometimes necessary. The minimum depth should be 3 feet for general farming or trucking, but for grass land the drains are as effective if placed not deeper than from 18 inches to 2 feet. In peat soils drains one-fourth to one-half mile apart are often sufficient.

The grade on which the tile is to be laid is largely to be governed by the height of the marsh above low water. The tendency is to use very few of the 1½-inch or 2-inch tiles, but to make 3-inch tiles the smallest used. The smaller tiles are found difficult to lay and keep in operation and the 3-inch tiles are not more expensive in the end and are much more effective.

WASHING OUT THE SALT.

In salt marshes the tile drains are for two purposes: First to remove the salt which has been left by the water, and second, to remove promptly any excess of water which may be present or fall on the marsh. In order that the salt may be removed it must be dissolved in water and that water drained away. The usual way of reclaiming the meadows is to allow the rain to wash out the salt. This is a slow practice, requiring usually two or three years, but during this time some crop can usually be grown. The sweetening can be accelerated by irrigation with fresh water, if such is at hand. When the land is to be reclaimed by irrigation small amounts of water should be applied at frequent intervals rather than a single heavy flooding. If small applications of water, not more than enough to cover the ground to a depth of from one to 4 inches, with sufficient time between the applications to allow the drains to carry away all the excess of water, be applied, the land can be sweetened in one season or less. If the natural sweetening process is followed, the native salt grass should be allowed to grow at first and tame grasses will gradually take their place as the salt is removed by the drainage.

When the cost of this method of frequent small floodings is found to be prohibitive the land may be flooded to any depth and that depth maintained. Reclamation in this way is successfully carried on, but only water-loving crops can be grown during the sweetening process.

CULTIVATION OF MARSH.

After the land has been diked and ditched the best method of cultivation must be settled upon. If the soil is a tidal mud or silt, without a covering of any kind, the cultivation can be commenced at once or at least as soon as part of the salt is leached out. A great variety of crops is adapted to such soils. Cleaning the land of all weed seed and giving it an opportunity to be thoroughly aerated and weathered, by planting for one or two years some cultivated crop, such as corn or sorghum, is recommended. After that time, the best crop to select is one suited to the locality; whether it be truck, hay, cabbage, celery, or small fruits will depend on the market and taste of the cultivator.

If, however, the tidal silt or mud, or eel-grass clay, as it is generally known, is not at the surface, but is covered by a sod formed of the partly decayed stems and roots of the salt grasses, a very different method of treatment is necessary in order to get the soil in condition to cultivate. If this sod is thin and well rotted, disking, deep plowing, and thorough cultivation will generally break it up and enable a good seed bed to be prepared; but when it is a foot or more deep, and is in turn underlain by half decomposed sod for a depth of a foot or two, the breaking up and incorporation with the underlying soil in a short time by cultivation are impossible. The best method of subduing such soil is to burn off the sod. When it is fairly dry to a depth of 12 inches fires should be started at a number of places and the sod allowed to slowly smoulder. The burning should be carried on until the eel-grass clay is close to the surface, or until the heavy roots are consumed. Then by rolling and plowing the soil can be worked into condition. Burning was formerly a practice in common use in European agriculture, and is yet continued in the marsh soils of northern Germany, Denmark, and Holland. The smoke of this burning is said at times to be noticeable as far as Italy. The sod is there burned to a depth of 10 or 12 inches only, and is then cultivated for from five to ten years and burned again.

Such a practice will in time burn the entire peat of the swamps and leave the underlying soil bare. The practice is very prodigal of organic matter and is not to be recommended in America, especially since there are crops which grow to best advantage in peat. In celery areas, where such peaty soils are handled, burning is not the usual practice; in fact, the organic matter is the desirable part of the soil for the production of celery. In such areas some cultivated crop is planted for one or two years to give the peat an opportunity to decay. Rather shallow open drains are dug and the soil slowly dried out. When the first plowing is done the peat is often wet and boggy, so that it is impossible to drive a horse across the bog. Ingenious farmers in California attach a board to the feet of the horse the first time a bog is plowed. Though most horses are not used to working with "tule shoes," as they are called, they soon learn the proper swing to give the feet and the work of plowing goes on nicely.

The judgment of the farmer must be the guide as to the best method to be used to bring the land into good tilth. As a rule burning is a waste of organic matter which in the later years of cultivation will be needed. However, it is frequently better policy to burn off troublesome sod and trust to later stable or green manuring to keep the supply of organic matter up to the standard.

As a rule salt marshes are well supplied with lime in the form of shells. Such soils in decaying will not need to be limed. Sometimes, however, the shells are not present and the soil is either acid in its natural condition or soon becomes so through the decomposition of the organic matter. Lime is then necessary to correct the acidity. Either shell marl or shell lime is usually obtainable at low cost near the coast.

Sulphide of iron is sometimes present in marsh lands and by its decomposition gives off hydrogen sulphide gas and soluble iron compounds or sulphuric acid, all of which are harmful to plants. Thorough aeration will remove the hydrogen sulphide, but the poisonous iron compounds are more difficult to get rid of. Weathering and aeration with the application of lime, both as carbonate and sulphate, are the best methods known for the correction of the toxic effect of iron in the soil. The iron is most often found only in spots and small areas which slowly yield to cultivation. Very seldom does it cover large areas.

CROPS DURING RECLAMATION.

As has been stated before, the easiest method of reclaiming the salt marsh is to make the best use possible of the native salt grasses and to allow the tame grasses to come in as the salt is removed by drainage. This process can be accelerated by seeding with small quantities of tame grass—timothy, red-top, and the rye grasses are all good—on the parts of the marsh which contain the least salt. Three years will probably be the maximum time required to get a stand of tame grass. If the time needed to complete this natural reclamation is too long the process can be hastened by irrigation to assist in washing out the salt, or salt-resisting crops may be planted. Asparagus, onions, sorghum, and beets withstand large quantities of salt in the soil, and if the soil is such as to be acceptable to any of these crops they will prove profitable.

AGRICULTURAL VALUE OF SALT MARSHES.

To determine the agricultural value of such lands several samples of the salt marsh areas around Oyster Bay, on Long Island, were collected and subjected to laboratory examination. These are very probably representative of much larger areas of salt marsh, and the results of their examination will no doubt prove of interest to owners of salt marshes all along the coast,

As has been indicated, there are many kinds of salt marshes and tidal flats—some merely bare mud flats without vegetation, and others with a heavy growth of grass and with a sod a foot or more thick. In any locality such differences are due to the age of the marsh; and the two cases mentioned can be considered as representing youth and old age in marsh growth.

Mechanical analyses of tide marsh soils from New York.

Locality of soil.	Sand.	Silt.	Clay.
	Per cent.	*Per cent.*	*Per cent.*
5379. Mud from tidal flat, west end Lloyds Harbor, 0-6 inches	13.2	44.8	42.0
5375. Subsoil from outer marsh, Center Island, 36-66 inches	28.0	44.9	27.1
5378. Subsoil from inner marsh, Center Island, 24-72 inches	38.0	37.1	24.9

Chemical analyses of tide marsh soils from New York.

Composition.	5379 Soil 0-6 in.	5374 Soil 0-36 in.	5375 Subsoil 36-66 in.	5376 Soil 0-12 in.	5377 Subsoil 12-24 in.	5378 Subsoil 24-72 in.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lime (CaO)	0.43		0.31			0.41
Potash (K_2O)	0.57		0.57			0.68
Phosphoric acid (P_2O_5)	0.16		0.14			0.12
Organic matter	7.18	29.00	5.36	34.70	25.49	10.90
Soluble in water	2.16	4.07	2.55	1.87	3.87	3.56

The two tables show the results of the laboratory examinations of the Oyster Bay samples. Sample No. 5379 was collected from the tidal mud flat in the west end of Lloyds' Harbor, and represents the soil on which the salt marsh grows, or, in other words, is the salt marsh in youth. At low tide this mud flat is only a foot or 18 inches above the level of the water in the harbor, but at high tide it is covered with salt water 4 or 5 feet deep. At the present time the eel-grass has just commenced to grow on the mud, and it is found in large, round hummocks dotting the mud flat. These hummocks will gradually spread until the eel-grass is growing over the entire flat. The growing grass greatly retards the flow of the water as the tide rises and flows and the deposition of the sediment will be hastened. The chemical analyses of this mud show it to be fairly rich in lime, abundant in potash and with an adequate supply of phosphoric acid. The 7 per cent of organic matter will keep the clay soil in good tilth. The amount of soluble matter (2.16 per cent), which an analysis showed to be almost entirely from sea water, would prevent useful plant growth other than salt grasses. The drainage of this flat would permit the washing out of this salt.

Two marshes on Center Island which are being drained were examined. These marshes—an inner marsh and an outer marsh—are separated by a narrow neck. Across this neck a causeway had been built and sluice gates placed in the culvert under the causeway. The gates were not carefully watched and the tide water backed up on the inner marsh several times. Notwithstanding this, the inner marsh was much fresher. The outer marsh, however, was covered at high tide twice a day and contained a large amount of salt. Both of these marshes had a sod about 1 foot thick and below this was decomposing sod to a depth of 3 feet and then came the eel-grass mud, very similar to that collected in the west end of Lloyds Harbor.

Samples No. 5374 and No. 5375 were taken from the outer marsh and represent the sod and decomposing grass roots and the underlying eel-grass clay, respectively. The plant food analysis of the clay shows it to be similar to the mud from Lloyds Harbor. The amount of soluble salt in both soil and subsoil is seen to be high for plants other than salt grasses. The sod is so light and tough that to decompose it thoroughly for a seed bed would require several years; therefore, it is likely that burning will be found the best method. It is interesting to note that the burning of these salt marsh soils causes part of the soluble matter to disappear, so that afterwards the amount of soluble matter is smaller than before burning.

Samples No. 5376, No. 5377, and 5378 were collected from the inner marsh. The first two are the sod and decomposing sod, respectively, and the last is the underlying eel-grass clay. The plant food analysis shows this clay to be very similar to the Lloyds Harbor mud. The percentage of soluble salts in the surface foot of the inner marsh is lower than that in any of the other samples. This shows that a start toward sweetening has been made by the simple shutting out of the sea water. The drainage of this inner marsh is in progress and three samples of the drainage water collected while the ditch was in process of construction showed a salt content of 525, 860, and 860 parts salt per 100,000 parts of water. If this drainage keeps up the marsh will in a short time be much sweetened. The soil in this inner swamp is also very light and should be burned if the intention is to cultivate it.

SUMMARY.

Salt marsh lands have long been considered the most fertile and valuable of lands. Practically no reclamation has been attempted in America, and that which has been attempted has in many cases been a failure or has been abandoned. There are well established methods in use in the reclamation of salt marshes and if these are used the work should be successful. There has never been a known case of failure to effect complete reclamation, in which all proper precautions were taken. After reclamation the lands are very fertile and should repay the expenditure for reclaiming them. It is generally conceded that 1 acre of reclaimed salt marsh land is worth 4 or 5 acres of upland, and, according to the well substantiated figures quoted from Shaler earlier in this article, the cost of reclamation should not exceed one-fifth of the final value of the land.

THOS. H. MEANS,
In Charge of Alkali Land Reclamation.

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United States Department of Agriculture.

BUREAU OF SOILS—CIRCULAR NO. 9.

MILTON WHITNEY, *Chief of Bureau.*

SOIL SURVEY AROUND IMPERIAL, CAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., January 10, 1902.

SIR: For some time an active interest has been taken in the development of what is known as the Colorado Desert in San Diego County, the extreme southern portion of California. This area is undoubtedly the site of an old inland sea which has long since dried up, leaving a basin, at the bottom of which is the Salton Sink at a depth of 280 feet below the present sea level, with a surface heavily incrusted with salts which are mined for domestic purposes. The rim of this basin is composed of soils which have been considerably modified by the occasional overflow of the Colorado River, which runs into this area for a short time every few years.

From the climate of this region, and the success that has been attained in the irrigation of a small area south of Yuma, it has been supposed that equal success could be attained here, provided water were available for irrigation. The country has frequently been compared with the Nile Valley, and the Department has looked to this area as a promising field for the introduction of Egyptian cotton, the date palm, and other crops imported from northern Africa.

After considerable agitation by engineers and capitalists a canal has finally been constructed from the Colorado River through about 60 miles of Mexican territory, and the water delivered at a point on the international boundary at Calexico, and sold there to mutual water companies for distribution to the land owners in this country. Although water was not available for irrigation until June, 1901, and then only over a small portion of the area, great many settlers have gone into the country, towns are springing up, a national bank has been organized, and a railroad is projected.

A number of requests were received by the Bureau of Soils for a soil survey of this area, so that some sure basis might be obtained for the establishment of agricultural industries. Such a survey has now been made of a portion of the area, comprising altogether about 169 square miles in the most important part of the irrigated district, and the condition of the soils, as regards the possibilities of their cultivation, the amount of alkali they contain, and their adaptation to crops, has been found to be much more serious than was anticipated. As the safe development of the country will have to follow certain definite lines, and as the enterprise is just starting, it is considered advisable to issue a preliminary circular, giving the results of the survey as a guide to the safe location of farms and the cultivation and care of the lands.

The soil survey shows that of the 169 square miles surveyed about 51 per cent is either too rough for economical irrigation or contains too high a salt content for any but the most alkali-resistant plants to withstand. The remaining 49 per cent of the area it is believed can be safely cultivated, provided suitable precautions are taken in the use of a proper amount of irrigation water, in the adoption of careful methods of cultivation, and, where necessary, in the installation of underdrainage to carry off the excess of seepage waters and alkali.

It is to be regretted that the whole area which it is proposed to irrigate could not have been surveyed; but the limited time which could be given to this locality by reason of the lack of sufficient appropriation and the pressure for work elsewhere made it impossible to accomplish more than has been done. The only safe basis upon which lands can be purchased and crops and methods of cultivation selected is a careful and systematic examination and survey of the soils which it is proposed to irrigate. This would require about six months and an expenditure of about $5,000, a sum which is not available in the appropriations for this Bureau. Such a survey would give a detailed map of every section of land, and an alkali map showing the condition of the soil regarding the presence of alkali salts to a depth of 6 feet or more; and would be a safe basis for the purchase of land and the development of the country.

If there is any general desire for the extension of this soil-survey work it would be well either to ask Congress for a special appropriation for this specific work or to arrange for some State or local cooperation which would enable the survey to be made in the near future.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

REPORT BY THOS. H. MEANS AND J. GARNETT HOLMES.

AREA SURVEYED.

The part of the Colorado Desert investigated by this Bureau extends from the international boundary line at the town of Calexico northward 21 miles. The area includes T. 14 S., R. 14 E., T. 15 S., R. 14 E., T. 16 S., R. 14 E., T. 16 S., R. 15 E., T. 17 S., R. 14 E., and T. 17 S., R. 15 E. The area is entirely within San Diego County, Cal., and lies about 115 miles east of the city of that name. Yuma, Ariz., is about 60 miles to the eastward.

Over the area mapped borings were made to a depth of at least 6 feet and were examined by the electrical method to determine the percentage of alkali salts. Note was made of conditions between the points of sampling, and from these data the soil and alkali maps given on pages 7 and 11 were constructed. Borings to a depth of 18 feet were taken at a few places to determine the amount of alkali in the deeper subsoil. In the field about 900 samples were examined. A number of samples were sent to the laboratories for analysis and for the additional information regarding the kind of alkali and for mechanical analyses.

TOPOGRAPHY.

The area mapped is a part of the delta of the Colorado River. The surface in general is apparently level—a smooth, gently sloping plain, admirably adapted for irrigation. The general fall is about 5 feet to the mile. Over the greater part of the area between Salton and New rivers no leveling whatever is necessary for irrigation, the surface being smooth, level, and practically devoid of vegetation.

Salton River enters the United States in the southeast corner of T. 17 S., R. 15 E., and flows in a general northerly direction to a point north of the area mapped, where it turns northwest and eventually empties into Salton sink. For the first 25 miles of its course in the United States its banks are low; but farther north bluffs 40 to 60 feet high are found on either side. New River crosses the international boundary 7 miles west of the Salton, flows northwest for 7 miles, makes a great bend toward the west, and flows back northeast, cutting the area mapped in the northwest corner of T. 14 S., R. 14 E., making a large area between the two rivers which is considered the best part of the delta in this country. Both the rivers are dry except in time of the highest floods in the Colorado, when water breaks over the divide and runs in them for a short time.

The areas shown on the soil map as sand dunes are covered with dunes and hummocks 3 to 15 feet in height. The leveling of such land will be found expensive, and at the present prices assigned to land will not prove profitable. However, should transportation facilities become better and land under cultivation bring a higher price than is now the case much of this dune land can be leveled and reclaimed. By far the greater part of the dunes are free from harmful quantity of alkali salts, and the porous nature of the material will prevent the rise of the alkali if the level of standing water is kept so low that the upward capillary movement is unable to raise the water from the water table to the surface of the ground.

Around the western, southern, and southeastern sides of Mesquite Lake the lands are in places badly gullied and the amount of good land is small. Other than these few exceptions the land of the desert is beautifully leveled for irrigation and requires but the throwing up of small levees to permit irrigation.

The topography is shown by the contour lines upon the soil map on page 7. These contour lines are made from levels along section lines, and therefore do not show the minor details of topography. We are indebted to the California Development Company for the base and topographic map.

All of this part of the delta is below sea level. The basin extends to Salton Sink, which is about 280 feet below sea level. The basin is surrounded by a well-defined beach line, which is approximately at sea level, showing that there has been very little accumulative elevation or depression since the basin was a part of the ocean. The favored explanation of the formation of the country is that the Colorado River filled in the basin near its mouth, the greater deposition being nearest the river, until this part of the sea was cut off, and became an inland lake, from which the water has evaporated.

The whole delta is deposited in regular strata from 0.01 inch to 2 or 3 inches in thickness, most of the soils presenting the appearance in cross section of a shale or argillaceous sandstone. These strata are for the most part horizontal—good cross sections being exposed in the cuts of New and Salton rivers. Along Superstition Mountain, about 15 miles west of Imperial, the sediments have been uplifted and broken, exposing the deposits to a great depth. An examination of this section shows that the same general character of deposits extends to a depth of 500 feet. Several species of shells are found on the surface of the desert. Mr. Simpson, of the Smithsonian Institution, has identified these shells as fresh or possibly brackish water species which are found living to-day under suitable conditions. These would indicate that the surface of the desert was formed from fresh water or water slightly brackish. The presence of other beach lines below the line of present sea level is supposed to show that there have been periods of partial refilling of the basin from the extreme floods of the Colorado River. Such a refilling on a small scale occurred in 1891, when the bottom of the basin at Salton was flooded. During these times of partial refilling with fresh water these fresh-water shells were either washed in with the sediments or lived along the mud flats covered with shallow water.

DEVELOPMENT OF THE IRRIGATION SYSTEM.

Ever since the Colorado Desert was surveyed in 1854, schemes have been discussed to bring the water of the Colorado River to the land. Actual work on surveys for the canal system began in 1891, when Mr. C. R. Rockwood became identified with a company whose first plans were to take the water out a few miles above Yuma, carry it down, and flume across the river—the water to be used on lands in Mexico. In the financial panic of 1893 this company went to pieces. The difficult engineering features of this project prevented it from again being seriously discussed. With great tenacity of purpose, Mr. Rockwood continued to devote his time and energies to interesting capital in irrigating at least a part of the desert, and the result was the formation in 1900 of the California Development Company. This company is made up of a corporation in both the United States and Mexico, since a part of the company's works and canals are in Mexico.

The California Development Company is a stock company, the shares of which may be disposed of at will by the owners. It is not the policy of the company to actually irrigate lands in the United States, but to sell water to mutual irrigation companies at the border line, these companies having contracts which specify that not more than 50 cents per acre-foot will ever be charged for water and that at least 1 acre-foot of water must be paid for each year on every acre of land owning water rights. These mutual companies are made up of the owners of the land who have purchased water stocks from the California Development Company, which stocks are made appurtenant to the land. Water stocks began selling at $8 with a $1 bond, acceptable as future payment of stock, issued for each of the $3 of the first payment, making these stocks actually cost but $5.75 per acre. The demand for land and stocks was so great that the company raised the price from time to time until now (January, 1902) stocks are selling for $20 per share, $5 cash, and the balance to be paid in five yearly installments. For the price paid for stocks the California Development Company builds all canals which are to be given to the mutual companies when they assume control in the different districts. An assessment will be made by these mutual companies for running expenses, which must be paid by the farmer in addition to the 50 cents per acre-foot for water.

THE SYSTEM AS PLANNED.

The heading of the canal is 7½ miles below Yuma, on the California side of the river. The water will be carried from this point in a large canal, or several smaller parallel ones, 8 miles to the channel of the Salton River, where the natural channel is used to carry the water about 60 miles westward, running through a tract of 100,000 acres in Mexico, owned by the California Development Company, to the area to be irrigated in the United States. It will be taken out of the Salton a little way below the international boundary line and carried into the United States in a large 60-foot-bottom canal, with a capacity of 25,000 inches, or 5,000 second-feet. This canal is to irrigate that part of the delta included between Salton and New rivers. After entering the United States for a short distance, this large canal is to be changed into two 30-foot canals, side by side; the object being to use one while the other is being cleaned. The other canals are planned to leave the Salton at various points to irrigate lands in Mexico and on the east side of Salton River and west side of New River in the United States.

PRESENT DEVELOPMENT.

Water was first brought to the area in June, 1901, in a small ditch along the route of the proposed larger one. This water is used for domestic purposes—water of stock and irrigating a small amount of land. The greater part of the main canal to the point where the 30-foot canals commence is finished. From this point one of the 30-foot canals is for the most part finished to Imperial, and many of the laterals are constructed. The permanent heading at the Salton River, 7 miles southeast of Calexico, consisting of combined heading and 8-foot drop, has been built, but beyond this there are no gates or checks yet in the main canal. In all likelihood no water except that in the small ditch will be available for crops the present season. About 125,000 acres of Government land have been filed upon.

WATER SUPPLY.

The water supply in the Colorado River is abundant, at least sufficiently so to supply all present demands. The water is very muddy when taken from the river, containing a great deal of fine sediment of a reddish-brown color, which must make the keeping of the canal clean quite a problem, but it can no doubt be done. It is rich in plant food and will aid greatly in preserving the fertility of the soils to which it is applied. The soluble matter in the water, according to all analyses available at this time, amounts on the average to less than 100 parts per 100,000 of water. In the soluble matter lime, calculated as sulphate, makes up 40 per cent, the remainder being magnesium, potassium, and sodium chlorids and sulphates, with probably 20 per cent bicarbonates. Carbonates have not been found in more than very small quantities, and the presence of the gypsum would preclude all possibility of the accumulation of black alkali in a well-aerated soil. The use of such water is attended with no risk, provided the soils are not allowed to become water-logged. The amount of plant food in solution and in suspension makes the water valuable as a source of strength and nourishment to growing plants.

SOILS.

The soils of this portion of the delta are very uniform, all having been formed principally by the deposition of the finer sediment of the Colorado River. In some places sand has been mixed with this finer soil, making a sandy loam, or even in small areas a sand.

Five types were recognized and mapped, all of which are in places excessively alkaline, and even in places where the surface 6 feet shows no accumulation the soil is underlaid by an alkali-bearing clay subsoil. The following table shows the areas of each type of soil:

Areas of different soil types.

Soils.	Acres.	Per cent.
Dune sand	29,840	27.7
Imperial sand	1,020	1.0
Imperial sandy loam	23,710	21.9
Imperial loam	30,410	28.0
Imperial clay	23,120	21.4
Total	108,100	100.0

SOIL MAP

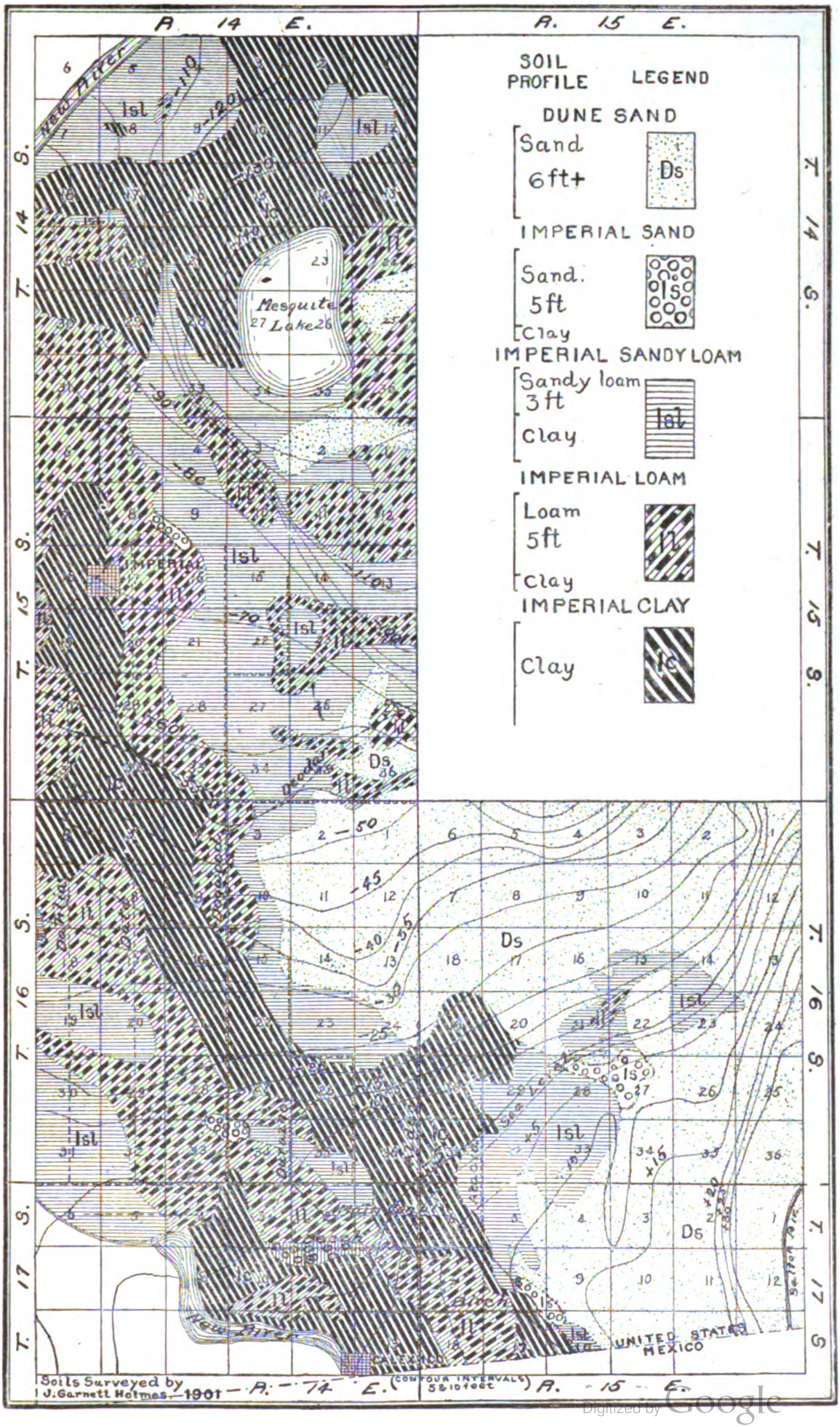


FIG. 1.—MAP SHOWING DISTRIBUTION OF SOIL TYPES IN THE IMPERIAL AREA, CALIFORNIA

DUNE SAND.

The sand dunes of the area mapped are found along the eastern boundary, limiting the irrigable land along Salton River. The dunes are from 2 to 10 feet high, crescent shaped, and very rough and unlevel. They have been formed by the strong winds of the valley. The sand is of a reddish brown color, 'rather rotten, and often mixed with small particles of flocculated soil. When wet these particles break down, producing a sandy loam soil. These dunes are underlaid by the heavier soils of the delta.

Owing to the strong winds which have formed these dunes and which would blow the sands around if leveled, and the roughness of the country, requiring great expense for leveling it. it is doubtful if these sand dunes are of present agricultural value.

The sand dunes are usually free from alkali salts, 95 per cent of the soil carrying less than 0.2 per cent alkali, but directly south of Mesquite Lake there is an area of sand dunes the western part of which contains a high percentage of alkali.

IMPERIAL SAND.

The Imperial sand is found in only small areas and is composed of the same material as the sand dunes, the only difference being that the surface is level enough to permit of leveling for irrigation. It is usually found in the vicinity of the dunes. Only small isolated areas were mapped. The surface soil is sand, 5 feet deep, underlaid by loam or clay loam which contains alkali. This soil will undoubtedly prove to be the best in the valley for all of the garden crops or any crop requiring cultivation. It is adapted to cultivated crops and fruits which will withstand this climate.

This soil will very likely always be well drained and practically free from alkali salts, but if the subsurface water should rise to within 6 or 8 feet of the surface by reason of excessive irrigation great danger should be feared of the accumulation of alkali. The cultivation of the sand is safe at present, but the movements of water and alkali salts in it are rapid, and should a subsurface accumulation of water be permitted the alkali would speedily rise to the surface and injure the soil. Eighty-two per cent of the soil has less than 0.2 per cent alkali, and 18 per cent from 0.2 to 0.4 per cent alkali.

IMPERIAL SANDY LOAM.

This soil is found scattered pretty generally throughout the area mapped, there being in all 37 square miles, or 24,000 acres. As a rule the surface is covered with small dunes, which consists of the sandy loam soil blown by the wind and lodged beside bushes and other obstructions. In T. 16 S., R. 15 E.; T. 16 S., R. 14 E.; T. 15 S., R.

14 E. the surface is wind-scored and very unlevel, while along the bluff southwest of Mesquite Lake, in T. 15 S., R. 14 E., the land is much cut by gullies, in some places 8 or 10 feet deep.

The sandy loam soil is formed by the coarsest sediment of the Colorado River deposit mixed with wind-blown sand. The sandy loam extends to a depth of 3 feet and is underlaid by a loam or heavy loam. This soil will take water readily, and where level and free from alkali is adapted to cultivated crops or alfalfa. Some of the best and some of the worst lands of the valley are composed of this type. A reference to the alkali map will show that this soil ranges in alkali content from practically nothing to more than 3 per cent. Thirty-seven per cent of the soil has less than 0.2 per cent alkali, 21 per cent has from 0.2 to 0.4 per cent, and 42 per cent has more than 0.4 per cent alkali.

IMPERIAL LOAM.

The Imperial loam was found to comprise a part of each township mapped. The surface is smooth and level as a floor, almost devoid of vegetation. It has the peculiar, slick, shiny appearance often seen in localities where water has recently stood. It is the direct sediment of the Colorado River which has been deposited in strata when the area was under water. These strata are from 0.01 inch to 2 or 3 inches thick, resembling shale very much, in fact, to all external appearances being exactly similar. When water is applied, however, the soil softens up and is a reddish sticky loam, a little heavier than a silt loam. It is from 4 to 6 feet deep, underlaid by a clay or clay loam, and contains considerable organic matter, including an abundance of nitrogen and potash. When free from alkali it is well adapted to the growth of wheat, barley, and alfalfa. This soil is in the main alkaline and in some places to such a degree as to preclude all possibility of profitable agriculture. Of the 30,000 acres mapped 16½ per cent has less than 0.2 per cent alkali; 21½ per cent has from 0.2 to 0.4 per cent, while 62 per cent has more than 0.4 per cent alkali.

IMPERIAL CLAY.

The Imperial clay as soil or subsoil is found throughout the entire area. It is usually comparatively level, although in some places small hummocks have been blown up on its surface. It is this soil that surrounds both the towns of Calexico and Imperial—the only difference in the soils of the two districts being in the alkali content. The soil has been formed by the deposition of the finest sediment of the Colorado River and is stratified in the same way as the loam. It is a heavy, sticky, plastic soil, very much resembling the clay subsoil found in the Mississippi River Delta. When dry and in its natural state it exists in hard cakes and lumps, which may be cut with a knife and is susceptible of taking a high polish. When wet the lumps are very plastic and sticky, making a refractory soil which it is very difficult to cultivate. Upon drying the soil becomes very hard and cracked. Sorghum and millet were grown this year on several hundred acres of this land in the vicinity of Calexico which produced good crops. The sorghum, however, was the best, the yield being 6 or 8 tons to the acre.

Cultivation of this clay soil will be very difficult. A similar soil is found in the Salt River Valley as a phase of the Glendale loess and is locally known as "slickens." The farmers of that neighborhood have considerable difficulty in managing this soil and it is not as refractory as much of the Imperial clay. Either annual crops or crops which can be cultivated throughout the growing season are productive of best results on this soil, for the heavy and hard crusts need to be broken up and thoroughly pulverized occasionally. Alfalfa does not do well on such a soil, for the crusts seem too hard and the soil too dense and impenetrable to permit the constant extension of the fine rootlets so essential to permanency in an alfalfa field. Deep plowing and thorough cultivation will in a few years greatly improve this soil.

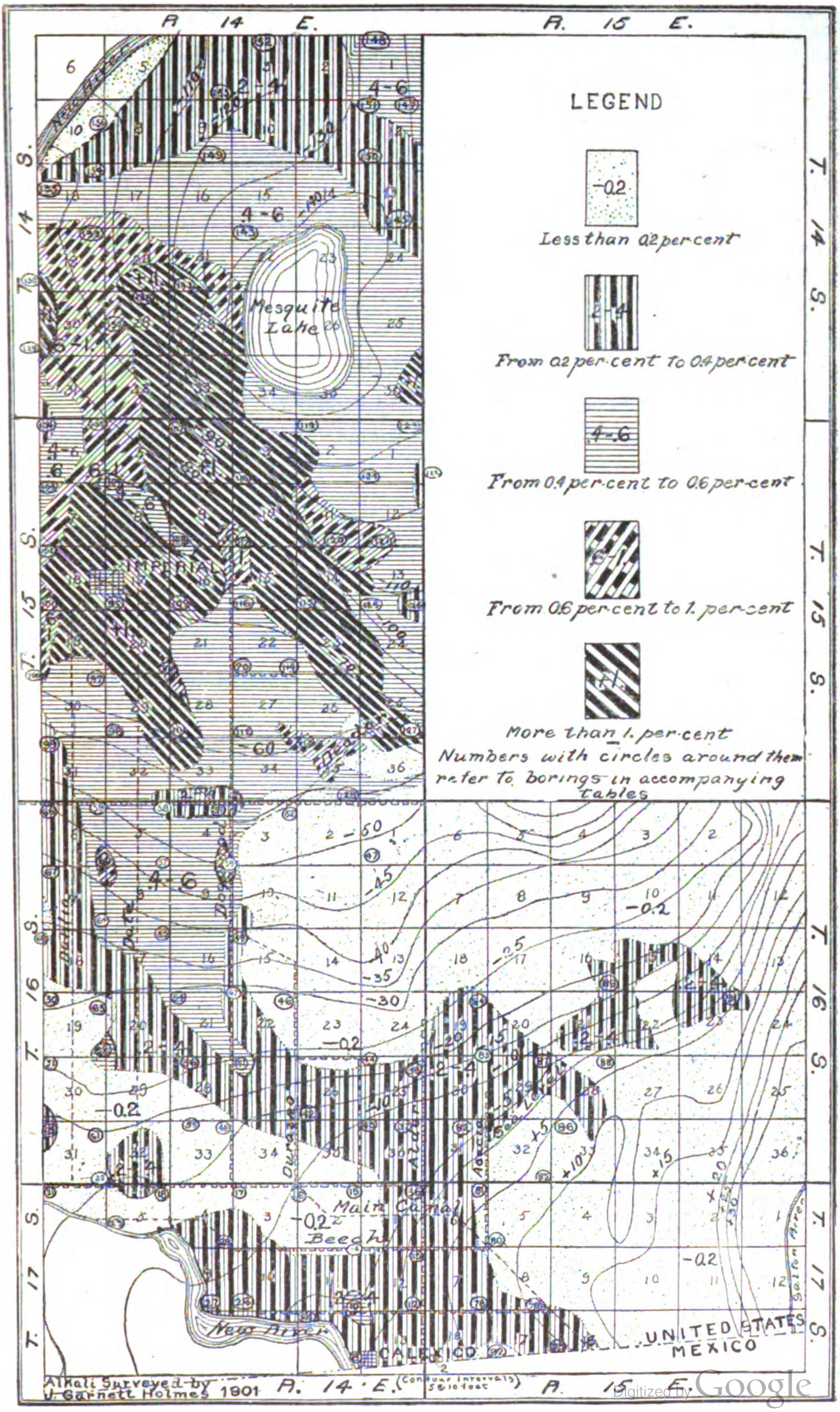
Aside from the difficulties in the physical properties of the soil, the greater part of it contains too much alkali to warrant its continued cultivation. Two or three crops may be taken off the land, but the rise of the alkali is almost inevitable, and the cultivation of soils containing more than 0.4 per cent alkali is not recommended.

In the area surveyed there were 23,000 acres of this soil. Of this, 3 per cent carried less than 0.2 per cent alkali, 43 per cent carried from 0.2 to 0.4 per cent, and 54 per cent had more than 0.4 per cent alkali.

ALKALI IN THE SOIL.

By popular usage any harmful accumulation in the soil of salts of any kind is referred to as alkali, distinctions being made between districts containing a large amount of sodium carbonate and those which do not. The sodium carbonate areas are popularly called "black alkali" areas, and all others "white alkali" areas. The white alkali salts are usually found associated with the sodium carbonate in black alkali areas, while in the white alkali regions there is usually a predominance of the sulphates or chlorides, with smaller amounts of other salts. So far as is yet known, the amount of white alkali that crops will withstand is influenced more by the presence or absence of lime as a constituent of the soil than by the chemical composition of the salts. It has been determined by experiment, both in the field and in the laboratory, that where there is an excess of lime in the soil in the form of sulphate or carbonate, plants will withstand a greater percentage of alkali than where the lime content is small. In the Colorado Desert gypsum (sulphate of lime) and carbonate of lime are nearly always present in the soil.

ALKALI MAP


R. 14 E.
R. 15 E.
T. 14 S.
T. 15 S.
T. 16 S.
T. 17 S.
LEGEND
-0.2
Less than 0.2 per cent
2-4
From 0.2 per cent to 0.4 per cent
4-6
From 0.4 per cent to 0.6 per cent
6
From 0.6 per cent to 1. per cent
+1.
More than 1. per cent
Numbers with circles around them refer to borings in accompanying tables
New River
Mesquite Lake
IMPERIAL
Dahlia
Date
Main Canal
Beech
Orange
Acacia
Alder
CALEXICO
Salton River
UNITED STATES
MEXICO
Alkali Surveyed by J. Garnett Holmes 1901
(Contour Intervals 5 & 10 feet)

CHEMICAL COMPOSITION OF THE ALKALI.

The alkali of this portion of the desert is all of the white kind, principally the chlorid of potassium and sodium. Lime is present both as sulphate and carbonate. No crops except sorghum and millet have as yet been grown, so the exact limitations for the different crops for this area were not established, although they certainly could not withstand a great deal more than the crops elsewhere. If the soils are kept well drained there is enough gypsum in the soil and water to preclude all possibility of there ever being an accumulation of the black alkali.

As the area is now below sea level, and the soils were most likely deposited in salt or brackish water when this was a part of the sea, and the alkali is principally common salt, the principal salt of the sea, we may directly conclude that the major part of the alkali came from the sea water, this alkali simply staying in the soil because the rainfall was insufficient to wash it out. The floods from the Colorado have brought in other salts, particularly sulphates, and much changed the chemical composition of the salts from their original composition as deposited from the sea.

The following table shows the results of the analysis of a mixture of eight samples of alkali crust collected from various places in the desert:

Analysis of mixture of eight samples of alkali crust from Imperial area, California, combined by a conventional method.

	Per cent.
$CaSO_4$ (calcium sulphate)	9.91
$MgSO_4$ (magnesium sulphate)	9.02
Na_2SO_4 (sodium sulphate)	.33
KCl (potassium chloride)	30.02
$NaHCO_3$ (sodium bicarbonate)	9.59
$NaNO_3$ (sodium nitrate)	8.91
NaCl (sodium chloride)	32.22
	100

The alkali exists either in the soil or subsoil throughout the area mapped. In many places where the soil is of open, porous nature this alkali has been washed out of the surface soil down into the subsoil, and in the case of the more sandy soils will very likely stay in the subsoil too deep to damage shallow-rooted crops, unless the soils are so filled up with water that the capillary power of the sandy soils can raise the standing water to the surface.

The alkali map accompanying this report (p. 11) outlines five grades of soil as to alkali content:

Grade of soil.	Acres.	Per cent of the area.
From 0 to 0.2 per cent	42,220	39.1
From 0.2 to 0.4 per cent	25,320	23.4
From 0.4 to 0.6 per cent	23,040	21.3
From 0.6 to 1 per cent	5,220	4.8
Over 1 per cent	12,300	11.4

These grades represent the average for the surface 6 feet, tests having been made for each foot in depth and the arithmetical mean taken. At the end of this report a table is given showing the per cent of alkali in each foot of depth for all the borings.

The 0 to 0.2 per cent grade is soil that is practically free from alkali. No crops but the most sensitive would be injured by this percentage. Almost all common crops will withstand from 0.2 per cent to 0.4 per cent. Barley, corn, alfalfa, watermelons, cantaloupes, and most of the berries, grapes, figs, apricots, and peaches will do almost as well in this grade of soil as in lands that contain much less, the chief danger in growing fruits being the fact that their roots are liable to go deep into the subsoil and thus reach the alkali accumulated there. Alfalfa will barely grow in the 0.4 to 0.6 per cent soil, even when well matured. If once a stand is secured it will struggle along, unless there be a concentration caused by the irrigation. Barley will produce a crop, though not first class. Pear trees will grow for a time at least, and if the subsoil be no worse than the surface and no concentration near the surface takes place they would thrive indefinitely.

All land that contains more that 0.6 per cent of alkali must be handled very carefully to produce any kind of crops except the most alkali resistant. Careful and proper methods of cultivation may result in washing enough of the alkali of the surface 2 or 3 feet into the subsoil so that shallow-rooted crops, such as annuals, can be grown. But until this surface reclamation takes place only such crops as sorghum, date palms, and sugar beets can be grown. On all the soils that contain more than 1 per cent of alkali date palms and saltbushes are the only crops that will thrive. In the Sahara date palms will grow on lands containing as much as 3 per cent of alkali.

The alkali map shows the conditions to a depth of 6 feet only, but as alkali salts have been known to rise to the surface from much greater depths, it is important to know the amount of alkali in the deeper subsoils. For this purpose deep borings were taken at a number of places. The following table shows the results of these borings:

Results of deep borings.

[Per cent alkali in each foot of soil.]

Depth in feet.	Boring 12, SE. cor. sec. 12, T. 17 S., R. 14 E.		Boring 44, NW. cor. sec. 25, T. 16 S., R. 14 E.		Boring 92, SW. ¼ sec. 17, T. 17 S., R. 15 E.		Boring 95, NE. cor. sec. 19, T. 15 S., R. 14 E.	
		P. ct.		*P. ct.*		*P. ct.*		*P. ct.*
0 to 1	Loam	0.19	Sandy loam	−0.20	Loam	0.37	Clay loam	1.80
1 to 2	Loam	.27	Sandy loam	− .20	Loam	.24	Clay loam	1.88
2 to 3	Loam	.25	Sand	− .20	Clay loam	−.20	Clay loam	1.85
3 to 4	Clay	.21	Sand	− .20	Sand	−.20	Clay loam	1.88
4 to 5	Clay	.28	Sand	− .20	Sand	−.20	Clay loam	1.23
5 to 6	Clay loam	.25	Sand	− .20	Loam	−.20	Loam	1.22
6 to 7	Clay loam	.24	Sand	− .20	Clay loam	−.20	Loam	1.40
7 to 8	Clay	.34	Sand	− .20	Clay	−.20	Loam	1.30
8 to 9	Clay	.36	Sandy loam	.82	Clay	.30	Loam	1.35
9 to 10	Clay	.37	Clay	1.34	Clay	.40	Loam	1.30
10 to 11	Loam	.22	Sandy loam	.70	Clay	.54	Loam	1.10
11 to 12	Clay loam	.36	Sandy loam	.62	Clay	.62	Loam	1.00
12 to 13	Clay loam	.50			Clay	.56	Loam	1.20
13 to 14	Clay loam	.48			Clay	.73	Loam	1.10
14 to 15	Clay loam	.39			Loam	.84	Sandy loam	.84
15 to 16					Loam	.67	Sandy loam	.84
16 to 17							Sandy loam	.96
17 to 18							Sandy loam	.90

Inspection of this table shows that at every deep boring alkali was found in more or less harmful quantity in the subsoil. Even in boring 44, where the soil was light throughout the top 8 feet and free from harmful quantity of salt, as soon as the clay was reached, at 9 feet, a high percentage of alkali was found. The irrigation of such soil would be perfectly safe as long as the level of standing water did not rise sufficiently for the surface to be kept wet by capillarity. Should this happen the rise of the alkali, even though buried 8 feet, would be certain.

Aside from the alkali, which renders part of the soil practically worthless, some of the land is so rough from gullies or sand dunes that the expense of leveling it is greater than warranted by its value. In the 108,000 acres surveyed, 29,840, or 27.7 per cent, is sand dunes and rough land. Of the total area level enough to permit profitable cultivation, 17 per cent contains less than 0.2 per cent of alkali and 32 per cent contains from 0.2 per cent to 0.4 per cent. The remainder of the land, or 51 per cent, contains too much alkali to be safe except for resistant crops.

CONDITIONS OF AGRICULTURE AND POSSIBILITIES OF IMPROVEMENT.

Perhaps more than any other part of arid America this lower desert portion of the Colorado River delta must depend upon agriculture and agriculture alone for its support. The nearest mining territory in any direction is miles away. The climate is not such that tourists or pleasure seekers will help maintain the country, as is the case in many other parts of the Southwest. Every dollar gotten from the country must come from the soil. To grow crops successfully in an arid country two things are absolutely necessary—the proper kind of soil and water. Experience long ago demonstrated that the greatest problem confronting the farmer in arid countries is the danger from harmful accumulations or the rising of alkali salts. Case after case is on record where either from the use of alkali-impregnated water or from the localizing of the small amount of alkali already in the soil large areas have been ruined, where when irrigation began there was no appreciable amount apparent in any of these soils. In nearly every irrigated region these alkaline areas seem to be a necessary adjunct. Much work has been done by the different experiment stations of the United States and this Bureau in the past few years in determining the amount of alkali various crops will withstand in these alkaline areas, and the following limitations have been established for the white alkali:

	Per cent.
Barley, sugar beets, sorghum	0.6 to 1.0
Alfalfa, wheat, corn	.2 to .4

Sorghum is an alkali-resisting plant and will very probably withstand more than sugar beets. By glancing at these figures and at the alkali map which accompanies this report it will be seen that for a great deal of the lands of the area mapped even the most alkali-resistant plants will not grow at the present time, before any accumulation at the surface has taken place from evaporation or concentration of seepage waters. The subsoil of all of the area is strongly impregnated with salts, a part of which must, in all except the very sandy soils, eventually reach the surface and greatly interfere with agriculture.

When looked at rationally it is easy to understand why this country is alkaline. It is part of an old desiccated sea bed and is all below the present sea level. The soils were deposited and saturated with sea water or brackish water, which evaporated and left them strongly impregnated with the salts in solution. The rainfall is so slight as never to penetrate the soils to any depth, so that very little salt has ever been washed out of them. Wells put down to subsurface water all over the valley find water which contains alkali—sometimes too much for domestic use. Salton salt works are at the bottom of the basin, where tons and tons of salt are taken from the surface of the ground each year, only to be replaced by the evaporation of seepage waters, which must, in part, be the drainage from this very country.

One hundred and twenty-five thousand acres of this land have already been taken up by prospective settlers, many of whom talk of planting crops which it will be absolutely impossible to grow. They must early find that it is useless to attempt their growth. On the bad alkali lands they should try to grow only crops suited to such lands. Test plots will be of very little value except for the year in which they are made. The land may produce a crop for a year, or even two years, and then, having become thoroughly saturated, the alkali will rise and kill the crops. For the worst lands the best thing to do will be to immediately abandon them.

Much can be done to benefit, at least temporarily, the alkali conditions of the delta by careful and intelligent methods of cultivation and irrigation. On the heavier soils as quickly as possible enough organic matter should be plowed under to ameliorate in a degree the impervious clay properties and allow a more rapid percolation of the water. Water should in all cases be applied to the surface. Only on the most sandy soils should furrow irrigation be practiced at all, for soon the furrows would be as white as the ditch banks already are throughout the district. The alkali is transported by the water; so if the water can be applied to the surface and be kept going down all the time, and the subsoil offers good drainage, then alkali lands can be reclaimed simply by copious surface flooding; but if, on the other hand, the soil be heavy and compact, not conducive to rapid percolation, then the tendency will be to fill up the soil with water— the alkali going down for a while and then again coming to the surface at the rise of the water table. This action is especially harmful if the subsoil contains a greater percentage of alkali than the surface.

So the permanent reclamation of alkali lands depends wholly upon the drainage, natural or artificial. If the natural drainage is not good, then artificial drains must be introduced. For the heavier soils of the delta artificial drains would have to be so close together that the expense would be too great to be practicable, at least for the present, so the natural drainage alone will have to be depended upon. Standing water at Colexico is less than 50 feet below the surface, while at Imperial it is less than 30, and at this point moisture comes to within 5 feet of the surface. Nearly all this subsurface water is salty, so if the water from the surface reaches this and raises it before it drains several miles laterally, then the conditions will be aggravated rather than bettered. If the whole country is irrigated at the same time sufficiently to wash the alkali down below the reach of plant roots, then the subsoil of the whole country will be filled and lateral drainage be very slow, so the reclamation of the lands already badly alkaline seems almost a hopeless task.

No doubt the best thing to do is to raise crops like the sugar beet, sorghum, and date palm (if the climate will permit), that are suited to such alkaline conditions, and abandon as worthless that which contains too much alkali to grow those crops. There is not rain enough to grow salt bushes without irrigation, but with irrigation they would do well, and serve as profitable food for cattle, sheep, or goats.

SUMMARY.

Farming in the desert to ordinary crops, fruit or alfalfa will be impossible on much of the land, and risky on all unless special precautions are taken to prevent the rise of the alkali. Of the level lands only 17 per cent have less than 0.2 per cent alkali, while 32 per cent have from 0.2 to 0.4 per cent. This 49 per cent of the area can be farmed to nearly all crops as long as the accumulation of the alkali at the surface is prevented. The remainder of the land, or 51 per cent, will have to be farmed to alkali-resistant crops. Date palms, sorghum, sugar beets, and barley will likely be most successful. Even where farmed to these resistant crops the greatest precaution should be taken to prevent an accumulation of alkali at or near the surface.

The claims for the fertility of this country are based upon the experience gained from irrigation along the Colorado River below Yuma. An examination of the country reveals the fact that the conditions below Yuma are very different from those in the Imperial area, and the agriculture of the two areas is not comparable. The soils of the bottom lands below Yuma are lighter in texture, more pervious to water, contain less alkali, and are, many of them, well adapted to alfalfa.

SALT CONTENT OF THE SOIL.

Boring No.	Location.	Type of soil.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Grade of land.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
2	SE. cor. sec. 18, T. 17 S., R. 15 E	Imperial clay	-0.20	-0.20	0.20	0.28	0.48	0.46	0.2 - 0.4
6	Cen. E. ½ sec. 7, T. 17 S., R. 15 E	do	.25	.24	.22	.22	-.20	....	.2 - .4
8	SW. cor. sec. 13, Calexico	do	.40	.87	.52	.25	.21	-.20	.2 - .4
10	NE. cor. sec. 14, T. 17 S., R. 14 E	do	.24	.44	.90	.46	.38	-.20	.4 - .6
12	SE. sec. 12, T. 17 S., R. 14 E	do	-.20	.27	.25	.21	.28	.25	.2 - .4
13	NE. cor. sec. 12, T. 17 S., R. 14 E	do	.25	.27	.26	.25	.26	.28	.2 - .4
14	NE. cor. sec. 11, T. 17 S., R. 14 E	Imperial sand	.20	-.20	-.20	-.20	-.20	-.20	0 - .2
15	NE. cor. sec. 2, T 17 S., R. 14 E	Imperial sandy loam	-.20	-.20	-.20	-.20	.22	.30	0 - .2
16	NE. cor. sec. 3, T. 17 S., R. 14 E	Imperial loam	.20	-.20	.22	-.20	-.20	....	0 - .2
17	NE. cor. sec. 4, T. 17 S., R. 14 E	Imperial clay	-.20	.22	.28	-.20	-.20	-.20	0 - .2
18	NE. cor. sec. 5, T. 17 S., R. 14 E	Imperial loam	-.20	-.20	-.20	-.20	-.20	-.20	0 - .2
19	S. cen. sec. 32, T. 16 S., R. 14 E	do	.64	-.20	.24	.32	.33	.33	.2 - .4
21	SW. cor. sec. 31, T. 16 S., R. 14 E	Imperial sandy loam	-.20	.24	-.20	-.20	-.20	-.20	0 - .2
22	SW. cor. sec. 32, T. 16 S., R. 14 E	do	-.20	-.20	-.20	-.20	.21	....	0 - .2
23	W. cen. SW. ¼ sec. 5, T. 17 S., R. 14 E	do	-.20	-.20	-.20	-.20	-.20	-.20	0 - .2
25	NW. cor. sec. 14, T. 17 S., R. 14 E	Imperial loam	-.20	.25	.32	.23	.29	.40	.2 - .4
26	SW. cor. sec. 10, T. 17 S., R. 14 E	do	.29	28	.52	.81	.21	-.20	.2 - .4
27	S. cen. sec. 9, T. 17 S., R. 14 E	Imperial clay	-.20	-.20	-.20	-.20	.22	-.20	0 - .2
28	SE. cor. sec. 4, T. 17 S., R. 14 E	do	.29	.32	.56	.47	.23	.22	.2 - .4
30	NW. cor. sec. 19, T. 16 S., R. 14 E	Imperial sandy loam	.63	.23	.22	-.20	.29	.34	.2 - .4
31	NW. cor. sec. 30, T. 16 S., R. 14 E	do	-.20	.21	-.20	-.20	-.20	.21	0 - .2
36	NE. cor. sec. 1, T. 17 S., R. 14 E	Imperial clay	.41	.28	-.20	-.20	-.20	-.20	.2 - .4
37	NE. cor. sec. 36, T. 16 S., R. 14 E	do	.44	.32	.20	.23	-.20	-.20	.2 - .4
38	NE. cor. sec. 25, T. 16 S., R. 14 E	do	.56	.23	-.20	-.20	-.20	-.20	.2 - .4
41	NW. cor. sec. 27, T. 16 S., R. 14 E	do	.21	.67	.58	.72	.70	.66	.4 - .6
42	SW. cor. sec. 26, T. 16 S., R. 14 E	Imperial loam	.32	.26	.35	.31	.43	.46	.2 - .4
43	NW. cor. sec. 36, T. 16 S., R. 14 E	Imperial clay	.50	.58	.31	.28	.24	.23	.2 - .4
44	NW. cor. sec. 25, T. 16 S., R. 14 E	Imperial sandy loam	-.20	-.20	-.20	-.20	-.20	-.20	0 - .2
46	NE. cor. sec. 22, T. 16 S., R. 14 E	do	.21	.32	-.20	-.20	-.20	-.20	0 - .2
47	NW. cor. sec. 22, T. 16 S., R. 14 E	Imperial clay	.51	.48	.29	.27	-.20	-.20	0 - .2
48	NW. cor. sec. 34, T. 16 S., R. 14 E	Imperial sand	-.20	-.20	-.20	-.20	-.20	-.20	0 - .2
49	NE. cor. sec. 16, T. 16 S., R. 14 E	Imperial loam	.38	.45	-.20	-.20	.30	.43	.2 - .4
50	NE. cor. sec. 9, T. 16 S., R. 14 E	do	1.60	1.10	1.00	.77	.59	.50	.6 - 1
51	NE. cor. sec. 4, T. 16 S., R. 14 E	do	.36	.60	.41	.26	.25	.20	.2 - .4
52	NE. cor. sec. 3, T. 16 S., R. 14 E	Imperal sandy loam	.21	-.20	-.20	-.20	-.20	.28	0 - .2
53	NE. cor. sec. 17, T. 16 S., R. 14 E	Imperial clay	.56	.60	.44	.34	.28	.29	.4 - .6
54	NE. cor. sec. 20, T. 16 S., R. 14 E	Imperial loam	.52	.51	.40	.38	.42	.46	.4 - .6
55	NE. cor. sec. 32, T. 16 S., R. 14 E	do	-.20	-.20	-.20	-.20	-.20	-.20	0 - .2
56	NE. cor. sec. 29, T. 16 S., R. 14 E	do	-.20	-.20	.30	.44	.41	.59	.2 - .4
57	NE. cor. sec. 8, T. 16 S., R. 14 E	Imperial clay	-.20	.33	.40	.38	.34	.22	.2 - .4
58	NE. cor. sec. 5, T. 16 S., R. 14 E	do	-.20	.32	.33	.26	.83	.25	.2 - .4
59	NE. cor. sec. 6, T. 16 S., R. 14 E	do	.30	.61	.50	.44	.42	.40	.4 - .6

60	NE. cor. sec. 7, T. 16 S., R. 14 E.	Imperial loam	.57	.74	.79	.79	.73	.66	.6 - 1
61	NE. cor. sec. 31, T. 16 S., R. 14 E.	Imperial sandy loam	.26	—.20	—.20	—.20	—.20	—.20	0 - .2
62	NE. cor. sec. 30, T. 16 S., R. 14 E.	Imperial loam	—.20	.21	.43	.85	1.22	.52	.4 - .6
63	S. E. cor. sec. 19, T. 16 S., R. 14 E	Imperial sandy loam	—.20	.21	.24	.20	—.20	—.20	0 - .2
64	NE. cor. sec. 18, T. 16 S., R. 14 E.	Imperial loam	—.20	.83	.50	.48	.50	.62	.4 - .6
65	NW. cor. sec. 31, T. 16 S., R. 14 E	Imperial sandy loam	.61	.37	—.20	—.20	—.20	—.20	.2 - .4
66	NW. cor. sec. 6, T. 16 S., R. 14 E	Imperial clay	—.20	.32	.29	.24	—.20	.23	.2 - .4
67	NW. cor. sec. 7, T. 16 S., R. 14 E	do	.38	.44	.24	.21	—.20	—.20	.2 - .4
69	NW. cor. sec. 18, T. 16 S., R. 14 E	Imperial sandy loam	—.20	—.20	—.20	—.20	—.20	—.20	0 - .2
70	SW. cor. sec. 22, T. 15 S., R. 14 E.	do	—.20	.58	.60	.76	1.00	.78	.4 - .6
72	6 miles NW. of Imperial	Imperial loam	1.60	1.60	.62	.31	.22	.28	.6 - 1
78	SE. cor. sec. 7, T. 17 S., R. 15 E	do	.86	.12	.24	.30	.38	.50	.2 - .4
79	SE. cor. sec. 8, T. 17 S., R. 15 E	Imperial clay	.38	.38	.22	.24	—.20	—.20	.2 - .4
80	NE. cor. sec. 7, T. 17 S., R. 15 E.	Imperial loam	.28	.36	.22	—.20	—.20	—.20	0 - .2
81	NE. cor. sec. 6, T. 17 S., R. 15 E.	Imperial sandy loam	—.20	—.20	—.20	—.20	—.20	—.20	0 - .2
82	NE. cor. sec. 31, T. 16 S., R. 15 E.	Imperial clay	.34	.33	.29	.33	.29	.28	.2 - .4
83	NE. cor. sec. 30, T. 16 S., R. 15 E.	do	.44	.38	—.20	—.20	—.20	.23	.2 - .4
84	NE. cor. sec. 19, T. 16 S., R. 15 E.	do	.58	.56	.51	.25	.18	.24	.2 - .4
85	NE. cor. sec. 5, T. 17 S., R. 15 E.	Imperial sandy loam	—.20	.22	.30	.20	—.20	—.20	0 - .2
86	NE. cor. sec. 32, T. 16 S., R. 15 E.	do	—.20	—.20	—.20	—.20	—.20	—.20	0 - .2
87	NE. cor. sec. 29, T. 16 S., R. 15 E.	do	—.20	.27	.43	.20	.23	.33	.2 - .4
88	NE. cor. sec. 28, T. 16 S., R. 15 E.	Imperial sand	—.20	—.20	—.20	—.20	—.20	.33	0 - .2
89	NE. cor. sec. 21, T. 16 S., R. 15 E.	Imperial sandy loam	.24	.50	.20	.24	.28	.22	.2 - .4
91	NE. cor. sec. 23, T. 16 S., R. 15 E.	do	.33	—.20	.24	.22	—.20	.22	.2 - .4
92	Cen. SW. ¼ sec. 17, T. 17 S., R. 15 E	Imperial loam	.37	.24	—.20	—.20	—.20	—.20	0 - .2
93	SW. cor. sec. 16, T. 17 S., R. 15 E.	Imperial clay	.21	.27	.28	.28	.18	.18	.2 - .4
95	NE. cor. sec. 19, T. 15 S., R. 14 E.	do	1.80	1.88	1.85	1.88	1.23	1.22	1+
97	NE. cor. sec. 30, T. 15 S., R. 14 E	do	.73	.94	.61	.47	.45	.47	.4 - .6
98	NE. cor. sec. 31, T. 15 S., R. 14 E.	do	.44	.48	.29	.30	.33	.32	.4 - .6
99	NW. cor. sec. 31, T. 15 S., R. 14 E	Imperial loam	.49	.31	—.20	—.20	.25	—.20	.2 - .4
100	NW. cor. sec. 30, T. 15 S., R. 14 E	do	.43	.40	.69	.82	.68	.80	.6 - 1
101	NW. cor. sec. 19, T. 15 S., R. 14 E	do	.59	.50	.45	.72	1.04	.87	.6 - 1
102	NW. cor. sec. 18, T. 15 S., R. 14 E	do	.71	1.02	.68	.62	.64	.64	.6 - 1
103	NW. cor. sec. 7, T. 15 S., R. 14 E	do	.79	.84	.25	.48	.42	.38	.4 - .6
104	NE. cor. sec. 7, T. 15 S., R. 14 E	do	.22	.69	.58	.32	.88	.60	.4 - .6
105	NE. cor. sec. 6, T. 15 S., R. 14 E	Imperial loam	.73	.66	.46	.83	1.00	1.02	.6 - 1
106	NW. cor. sec. 6, T. 15 S., R. 14 E	do	.37	.55	.28	—.20	—.20	—.20	.2 - .4
107	NE. cor. sec. 5, T. 15 S., R. 14 E	Imperial sandy clay	+3.00	3.00	+3.00	+3.00	3.00	3.00	1+
108	SE. ¼ sec. 8, T. 15 S., R. 14 E	Imperial loam	—.20	—.20	.51	.89	.81	.53	.4 - .6
109	NE. cor. sec. 20. T. 15 S., R. 14 E	do	+3.00	+3.00	+3.00	3.00	3.00	1.86	1+
110	NE. cor. sec. 29, T. 15 S., R. 14 E	Imperial sandy loam	.24	.73	.72	.56	.76	.63	.6 - 1
111	NE. cor. sec. 32, T. 15 S., R. 14 E	Imperial loam	.69	1.22	1.02	1.25	1.25	1.20	1+
112	NE. cor. sec. 33, T. 15 S., R. 14 E.	Imperial sandy loam	—.20	—.20	.22	.44	1.07	.79	.4 - .6
113	NE. cor. sec. 34, T. 15 S., R. 14 E.	Imperial loam	1.06	1.61	.63	.28	.64	....	.6 - 1
114	NE. cor. sec. 27, T. 15 S., R. 14 E.	do	.76	.89	.66	.41	.26	.31	.4 - .6
115	NE. cor. sec. 22, T. 15 S., R. 14 E.	Imperial sandy loam	.66	1.85	1.21	1.25	1.41	1.62	1+
116	NE. cor. sec. 21, T. 15 S., R. 14 E.	do	—.20	—.20	.85	.72	.56	.26	.4 - .6
117	NE. cor. sec. 16, T. 15 S., R. 14 E	do	1.04	1.07	.72	.51	.29	.45	.6 - 1
118	NE. cor. sec. 9, T. 15 S., R. 14 E.	Imperial loam	+3.00	+3.00	2.01	....	1.08	1.45	1+
119	NE. cor. sec. 3, T. 15 S., R. 14 E	Imperial sandy loam	—.20	—.20	.47	.73	1.88	.98	.6 - 1
120	S. cen. sec. 11, T. 15 S., R. 14 E.	Imperial loam	1.10	.74	.44	.54	.75	1.10	.6 - 1
121	S. cen. sec. 12, T. 15 S., R. 14 E.	do	1.02	1.22	.50	.41	.37	.44	.6 - 1

Salt content of the soil—Continued.

Boring No.	Location.	Type of soil.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Grade of land.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
122	NE. cor. sec. 12, T. 15 S., R. 14 E	Imperial loam	.66	.49	.25	- 0.20	-0.20	-0.20	.2 - .4
123	NE. cor. sec. 1, T. 15 S., R. 14 E	do	.48	.86	.54	.36	.40	.52	.4 - .6
124	N. E. cor. sec. 11, T. 15 S., R. 14 E.	do	.44	.38	.47	.35	.27	.37	.4 - 6
125	N. E. cor. sec. 23, T. 15 S., R. 14 E.	do	.80	.62	.32	.28	.28	.36	.4 - .6
126	N. E. cor. sec. 24, T. 15 S., R. 14 E.	do	-.20	-.20	.46	.41	.31	.35	.2 - .4
127	N. E. cor. sec. 36, T. 15 S., R. 14 E.	do	+3.00	+3.00	1.92	1.01	.90	.91	1+
128	S. E. cor. sec. 35, T. 15 S., R. 14 E.	Imperial sand	.29	.40	.40	.26	.25	1.00	.4 - .6
129	S. W. cor. sec. 30, T. 14 S., R. 14 E.	Imperial loam	3.00	2.02	1.19	.55	.42	.24	1+
130	S. W. cor. sec. 19, T. 14 S., R. 14 E.	Imperial clay	3.00	2.14	.71	.62	.48	.41	1+
132	E. cen. sec. 30, T. 14 S., R. 14 E.	do	1.30	1.74	1.00	.59	.55	.50	.6 - 1
133	NE. cor. sec. 19, T. 14 S., R. 14 E	Imperial loam	1.02	.90	.66	.61	.58	.58	.6 - 1
134	NE. cor. sec. 18, T. 14 S.. R. 14 E	Imperial clay	.39	.45	.25	.20	-.20	-.20	.2 - .4
135	W. cen., sec. 18, T. 14 S., R. 14 E	Imperial loam	.83	.68	.41	.43	.37	.33	.4 - .6
138	N. cen., sec. 29, T. 14 S., R. 14 E.	Imperial clay	1.06	3.00	2.04	1.60	1.24	1.24	1+
142	NE. cor. sec. 29, T. 14 S., R. 14 E	do	+3.00		+3.00		+3.00		1+
143	NE. cor. sec. 21, T. 14 S., R. 14 E	do	.77	.65	.51	.30	.25	-.20	.4 - .6
145	N. cen. sec. 4, T. 14 S., R. 14 E	Imperial sandy loam	-.20	.22	.22	.27	.45	.56	.2 - .4
147	NE. cor. sec. 12, T. 14 S., R. 14 E	Imperial clay	.70	.46	.39	.39	.39	.38	.4 - .6
148	NW. cor. sec. 1, T. 14 S., R. 14 E.	do	.57	.56	.42	.33	.32	.31	.4 - .6
149	N. cen. sec. 16, T. 14 S., R. 14 E.	do	.33	.56	.57	.46	.42	.38	.4 - .6
150	NE. cor. sec. 14, T. 14 S., R. 14 E.	Imperial sandy loam	.64	.76	.43	.25	.23	-.20	.2 - .4
151	NE. cor. sec. 11, T. 14 S., R. 14 E.	do	.71	1.00	.59	.46	.34	.29	.4 - .6
152	N. cen. sec. 3, T. 14 S., R. 14 E.	Imperial clay	.43	.43	.29	.22	.14		.2 - .4
153	NE. cor. sec 9, T. 14 S., R. 14 E.	Imperial sandy loam	.20	.42	.85	.27	.22	.21	.2 - .4
156	E. cen. sec. 7, T. 14 S, R. 14 E	do	-.20	.23	.20	-.20	-.20	-.20	0 - .2

S. 90.

United States Department of Agriculture,
BUREAU OF SOILS—CIRCULAR No. 10.
MILTON WHITNEY, *Chief of Bureau.*

THE USE OF ALKALINE AND SALINE WATERS FOR IRRIGATION.

During the summer of 1902 a representative of the Bureau of Soils visited the oases of the Oued Rihr country in the Desert of Sahara in eastern Algeria. In these oases artesian waters carrying very large quantities of soluble matter are used successfully for irrigation. From the information gathered there, and from experience in this country, it seems that the amount of soluble matter allowable in an irrigation water has been greatly underestimated by American writers, and that many sources of water which have been condemned can be used with safety and success, provided the proper precautions are taken to prevent the accumulation of the salts. As the precautions are those which should be taken by every irrigator, even if pure water is used, it seems an important matter to bring before the American people the methods in use in the Sahara.

The staple crop grown by the Arabs in the oasis country is the date, the fruit of a palm tree known to be one of the plants most resistant to alkaline or saline conditions of the soil, but in addition to this considerable quantities of the deciduous fruits, garden vegetables, and alfalfa are produced for home consumption.

Some of the vegetables successfully grown are those considered sensitive to alkali, and yet they were being irrigated with water containing in some instances as much as 800 parts of soluble salts to 100,000 parts of water, sometimes as high as 50 per cent of the salts being sodium chloride.

The limit of concentration for irrigation water in the United States, even where only the most resistant field crops are to be grown, has been placed by some authorities at 30 parts sodium chloride (common salt) or sodium carbonate (black alkali), and at from 170 to 300 parts of the less harmful salts, per 100,000 of water. The Bureau of Soils, however, several years ago insisted that water of a somewhat higher salt content might be used if the soil had good natural drainage, or artificial drainage were supplied, and the methods of irrigation were modified to suit the different conditions. Thus in 1899[1] the following statements were made after a study of soils and alkali conditions in the Pecos Valley, New Mexico:

> Next to the ownership of the land and the labor questions, the most important cause of the trouble in the larger portion of the Pecos Valley is the high salt content of the irrigation water, especially in certain seasons.
>
> At Roswell the principal water supply contains about 76 parts of soluble matter in 100,000 parts of water. At Hagerman this is increased to about 200 parts; at Carlsbad, to 240 parts; at Florence, to 280 parts; Red Bluff, 316 parts; at Pecos City, Tex., to 400 parts; and below Pecos City to over 500 parts. Five

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[1] Rept. 64, Field Operations, Division of Soils, 1899.

hundred parts of soluble matter may be taken as the extreme limit of endurance for plants, while 250 or 300 parts mark the danger point at which the results of the use of the water are very uncertain..

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The limit of endurance for most cultivated plants in a water solution is about 1 per cent or 1,000 parts of the readily soluble salts in 100,000 parts of water, but it must be remembered that in field culture the water is applied to soils already containing more or less of these salts, and also that evaporation and consequent concentration immediately set in after the application of water. It was found at Carlsbad that about 300 parts of soluble matter per 100,000 parts of water marked the extreme limit of safety of the use of water at that place.

* * * * * * *

One thing should be said in connection with the Carlsbad area, which seems rather anomalous in view of the statements of other investigators, namely, that with a water supply so near the limit of crop endurance as this becomes at times and in those areas in which there is already a large accumulation of salts, economy in the use of irrigation water, which is generally recommended in alkali regions, is one of the worst methods which can be practiced. Where the soil contains a relatively large amount of salt and but little water containing much salt is frequently applied, the ordinary evaporation will increase the salt content of the soil to such an extent that crops can no longer survive, whereas if adequate drainage is provided, and a large amount of water is used, the excess of salt resulting from the evaporation of previous applications of water may be removed, and the soil moisture be maintained at nearly the same concentration as the water supply.

The fact that the Arabs in Algerian oases are actually growing sensitive plants by the aid of irrigation waters containing from 400 to 800 parts of soluble salts, in some instances 50 per cent sodium chloride, shows that the Bureau has been on the conservative side in its estimates, and should encourage a more hopeful feeling among the people occupying areas where only alkali water is available for irrigation.

The prerequisite to the use of water of high salt content in irrigation is the knowledge that the methods employed are opposed to the teachings of most American writers on the subject. Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

The methods in the oases are quite different. The Arab gardens are divided into small plots, about 20 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained, there is little opportunity for the soil water to become more concentrated than the water as applied, and the interval between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

The native gardens are situated in the date palm groves and the vegetables and fruit are grown in the partial shade cast by these trees. The natives not only have the question of very saline irrigation waters to contend with, but the soils originally are often very alkaline. In three years they reclaim land too salty to grow the minor crops, using the saline water for that purpose, following the same plan of drainage and weekly irrigation as where crops are growing. One garden situated on the side of a salt flat and originally very saline was visited. Here alfalfa was in very good condition, and fig, pomegranate, melon, tomato, cabbage, pepper, and other plants were growing luxuriantly. The reclamation of this plot by irrigation twice a week had taken three years.

The native gardeners exercise great judgment in adapting their crops to the soil conditions. Where most alkaline the date palm alone is found; in other parts of the grove are grown the fig and pomegranate, and in other parts the vegetables less resistant to alkali. The amount of salt in the soil sufficient to injure the palm was not determined, but the French were unsuccessful in an attempt to establish a grove, the water used in irrigation being taken from a salt pond and containing, according to field determinations, 3 parts sodium carbonate, 5 parts sodium bicarbonate, and 1,036 parts sodium chloride in 100,000 parts.

The irrigation water is all drawn from artesian wells. A number of samples were sent in to the laboratory for analysis, the results of which are shown in the following table. These are fair average samples of the irrigation waters in use, and do not represent by any means the maximum of salinity. Field tests showed as high as 816 parts to 100,000 water in actual use on soils growing vegetables.

Chemical analyses of artesian water used in irrigating gardens in Sahara oases, Algeria.

Constituent.	Well at oasis Tabes-best.	Well at oasis Kudi Asli.	Well at garden of Ben Hadriah.
	Per cent.	*Per cent.*	*Per cent.*
Ions:			
Calcium (Ca)	9.92	4.19	9.86
Magnesium (Mg)	4.52	6.02	4.26
Sodium (Na)	14.03	20.48	14.18
Potassium (K)	4.27	2.35	2.72
Sulphuric acid (SO_4)	34.38	29.43	27.59
Chlorine (Cl)	28.06	36.21	27.05
Bicarbonic acid (HCO_3)	5.02	1.82	24.34
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	33.04	14.23	24.90
Magnesium sulphate ($MgSO_4$)	13.63	24.29	7.04
Magnesium chloride ($MgCl_2$)	7.23	4.41	16.72
Potassium chloride (KCl)	8.12	4.48	5.19
Sodium bicarbonate ($NaHCO_3$)	6.92	1.81	33.54
Sodium chloride (NaCl)	31.06	50.78	12.61
Total solids in 100,000 parts water	601.50	408.10	571.90

Enough has been written to show that much more can be done with alkaline irrigation water than has hitherto been generally thought possible, and while the intensive culture of the Algerian gardeners is not suited to our Western conditions, there is believed to be no reason why their methods can not be adapted, even with an improvement in point of economy, to more extensive cropping of the soil.

The soils in the Pecos Valley are not unlike those of the oases, and the general conditions in the two places are somewhat similar, although the irrigation water, even at the lowest stage of the Pecos River, is not as alkaline as the artesian water of the desert, nor are the soils naturally as alkaline. Employing the Algerian method of frequent irrigation with generous amounts of water on land well drained by open ditches or tile drains, large areas now out of cultivation might be used to grow alfalfa, truck, and other crops.

It is believed that the information conveyed in this circular will be of great value to the people of this country residing in regions affected with alkali, and that it will result ultimately in bringing into cultivation much land that has hitherto been thought worthless because of the character of the water available for irrigation.

THOMAS H. MEANS,
In Charge of Alkali Reclamation Work.

Approved:
JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *July 1, 1903.*

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United States Department of Agriculture,

BUREAU OF SOILS—CIRCULAR No. 11.

MILTON WHITNEY, *Chief of Bureau.*

RECLAMATION OF ALKALI LAND AT FRESNO, CALIFORNIA.

At the time of settlement of the country south of Fresno there was little indication of the presence of alkali in the soil and no one then suspected that serious damage would result from irrigation. When, after a few years, alkali commenced to show in the vineyards and orchards the attention of thoughtful men was directed toward remedying the evil, but up to the time of undertaking the experiment reported in this circular nothing effective had been accomplished.

In 1900 a party from the Bureau of Soils spent a season in studying the soil conditions around Fresno, and in a report, embodied in the report on field operations of the Division of Soils for 1900, recommended drainage, with frequent cultivation and copious irrigation during reclamation, as the solution of the alkali problem.

Notwithstanding the recommendations in this report and the repeated statements in subsequent reports on alkaline areas in different parts of the country that drainage is a practicable and the only safe and sure means of permanently reclaiming alkali lands, no steps had been taken by persons most deeply interested to check or remove the evil. The Bureau of Soils, after careful consideration, decided that the most convincing way of bringing the truth of its recommendations and the value of drainage in reclamation work before the people was to demonstrate it by the actual reclamation of some of the alkali land. For this purpose the Bureau selected a 20-acre tract of land belonging to S. M. Toft and N. H. Hansen, situated on Fig and Central avenues about 2½ miles south of Fresno and entered into cooperation with these gentlemen to demonstrate to the people of the irrigated region that alkali lands can be easily and economically reclaimed.

The history of this land, as given by the owners, is as follows: The northern part of the tract was settled upon by Mr. Toft in 1876 and at that time showed no sign of alkali. In 1889 Mr. Toft bought an additional 20 acres at $350 an acre, an average value for land in that vicinity at that time. The southern part of the tract was first settled upon in 1862 by Mr. Hansen and at that time was partially alkaline. It has never produced good crops. In 1890 alkali commenced to show on the northern part, and in 1898 and 1899 it was practically abandoned.

The tract lies in a level district where it was impossible to obtain a gravity outlet for the drainage water, except by digging a drain 2 miles long, so in order to raise the drainage water to the surface of the ground a chain pump operated by a water wheel was installed on Central Canal, where it crosses Fig avenue. A drainage system of this kind is admittedly not so desirable as one in which a gravity outlet can be maintained.

Three-inch, 4-inch, and 6-inch tile were laid over the tract at an average depth of a little over 3 feet and 150 feet apart. The original intention was to use nothing smaller than 4-inch tile, but the makers were unable to supply enough tile of this size, so the deficiency was made up by using 3-inch tile. It was found impossible to lay the tile during the summer season, owing to the nearness of the water table to the surface and the resulting condition of the subsoil, which was too soft to permit the digging of a deep ditch. The work of ditching was commenced in December, 1902, and was completed in February, 1903. The cost of ditching, tiling, and all incidentals except the cost of pump and water wheel amounted to $16.50 per acre. The contract for the tile delivered in Fresno was for 3-inch tile, $24 per thousand, for 4-inch tile, $32 per thousand, and for 6-inch tile, $72 per thousand.

At the time of the installation of the drains 18 acres of the land contained too much alkali to produce a crop. Scattered over a part of the tract were small patches of alfalfa and an occasional fruit tree—remnants of former cultivation. About the 1st of March, 1903, irrigation was commenced. The land was divided into 30 checks, the size of each check depending upon the slope of the land. The largest checks, those on the level land, are about 2 acres in extent, while on the steeper slopes they are less than half an acre. The object was to divide the land in such a way that it could all be kept under water to a depth of 4 inches, and the reclamation was to be accomplished by maintaining the water at this depth until enough alkali had been washed out of the soil through the drains to enable a crop to be grown.

During the progress of flooding many difficulties were met, among them that of keeping the tiles from partially filling with sand and silt. Precaution was taken in laying the tile to put them in so the joints would be close, hay was thrown over the tile in the ditch before covering with earth, and a ridge of earth was thrown up to prevent the water from standing directly over the drains. In spite of these precautions the soil, which is very light, was so easily moved by water that it seemed to enter the joints almost as readily as did the water. This resulted in some of the drains becoming clogged, and it was necessary to relay a portion of the tile. After the land had been once thoroughly soaked and had settled, no difficulty was experienced from filling of the drains and it is hoped that there will be no further trouble from this source. Most of the trouble was with the 3-inch tile, which is admittedly too small for use in soils of the light and silty character of the Toft-Hanson field. It is thought that there will be more or less silting up of the tiles whenever they are used in the sandy and white ash soils of the Fresno district, and it is recommended that every possible precaution be taken in putting them in. Much of the trouble may be obviated by using no tile smaller than 4 inches, or preferably 6 inches in diameter, and by giving the laterals such fall that the velocity of the water will be great enough to wash out the sand as rapidly as it enters the joints. The tile on the Toft-Hansen tract have a fall of 1 in 1,000 and the velocity of the water flowing through them is not sufficient to remove the sand. With a fall of 1 in 500 the velocity is great enough to remove practically all of the soil as fast as it enters.

To prevent entirely the clogging of the tile with sand, and to insure the removal of roots should any chance to enter, it is thought advisable to place in all tile a quarter inch galvanized strand-wire rope. Then two or three times a year, or oftener if necessary, a wire brush should be dragged through the tile in order to cut out all roots and stir up the sand and silt. Wire rope of this kind can be bought for about 1 cent a foot. Six-inch and 8-inch drains have been in operation for twelve years in the Sunnyside vineyard and have been kept in perfect order in this way. From the experience gained the Bureau can unhesitatingly recommend tile for drainage purposes, provided proper precautions are taken in its installation.

On July 15, 1903, after four and a half months of irrigation, an examination was made of the tract to determine what percentage of the land was sufficiently sweetened to grow a crop. This examination indicates that all of the land, with the exception of small spots amounting in the aggregate to less than 2 acres, is now ready for a crop. Most of it is sufficiently freed from alkali to warrant the sowing of alfalfa, but as midsummer is not the best time of year for seeding that crop, sorghum and Egyptian clover are being put in instead. These crops will mature by fall if the supply of irrigation water does not fail, and in the winter the land will be seeded to alfalfa. The small spots which are not yet ready for alfalfa are rapidly approaching that condition and will be ready for a crop during the coming winter. Thus it will be seen that practically all the land in this 20-acre tract has been returned to a state of profitable cultivation in a period of four and a half months after irrigation was commenced, and the statement seems justified that any alkali land in the Fresno district can be brought into profitable cultivation in less than one year's time, the two requisites for this being underdrainage and a copious supply of water for irrigation. While the Bureau considers the land of the Toft-Hansen field practically reclaimed at the present time, the demonstration will be continued until a satisfactory stand of alfalfa is secured.

GENERAL RECLAMATION IN THE FRESNO DISTRICT.

Having demonstrated that alkali land can in a remarkably short time be brought back into a state of fertility by underdrainage and flooding. it remains to indicate the most economical plan of extending the work to cover the larger districts affected by alkali or seepage water, or in danger of becoming thus affected.

That the rise of alkali is caused by a rise in the level of standing water in the soil is admitted by all, so that the solution of the alkali problem depends upon the solution of the drainage problem. It must not be supposed, however, that drainage alone will reclaim the alkali lands, for complete reclamation demands heavy irrigation or washing of the soil. In the case of the 20-acre tract now being reclaimed, it is seen that four and a half months' constant irrigation was necessary before a crop could be grown.

Anything, however, which lowers the water table will assist in the reclamation of the alkali lands and will allow of heavier flooding to effect this reclamation. Thus it is evident that if the bottoms of all irrigating canals were cemented and the loss of water by seepage prevented there would be a prompt falling in the level of standing water and heavier irrigation would be possible, thus enabling large areas of alkali land to be reclaimed by washing the alkali into the subsoil. This alone, without drainage, would not be a permanent removal of the alkali, for if the water table should by any means be raised again the alkali would promptly reappear at the surface. It is likely that the water table would be raised eventually, for upon the cementing of the canals and the consequent drop in the water level vines, trees, and plants with their root systems adjusted to the present water level would suffer and irrigation would be necessary in fields that now are never watered from the surface. It is also likely that all the water saved from seepage through the canal bottoms would eventually be applied to the land from the surface. Probably a larger proportion of this water would be lost by evaporation than now, but it is extremely doubtful if the conditions would be bettered. Again, if the farmers understood the proper amount of water to use and used only that amount, keeping the soil in the most perfect condition as regards moisture, much water might be saved and the water table lowered to such an extent that drainage would be unnecessary and satisfactory crops could be produced. But it is difficult to get the farmers to use just the right amount of water in practice, as they have a tendency always to apply it in excess. To drain the excess away before damage to the land results is the problem before the people.

Another scheme for reclamation is presented by Mr. J. B. Lippincott in his report, issued by the U. S. Geological Survey, on "Water Storage in Kings River." Mr. Lippincott proposes to establish electric power plants in the mountain canyons of Kings River, to transmit this power to the plains and to distribute it to the farmer for use in running pumping plants. With cheap power of this kind pumping plants could be used on the Fresno plains at points not reached by canals, or, even during a season of short supply, on lands under existing canals. Pumping would tend to lower the water table, and as probably 50 per cent of the water applied to the land would be lost by evaporation and transpiration by vegetation, there would result a permanent lowering of the level of underground water. For the lowering to amount to much rather extensive pumping would be necessary, and to accomplish this a cheap power must be had. This lowering of the water table would have the same effect as drainage and would permit the reclamation of alkali land.

During the winter months the level of standing water falls, the average depth being from 6 to 10 feet and in some places even more. This level is manifestly lower than could be obtained by any drainage scheme and if maintained would obviate the necessity for artificial drainage. A great deal could be done towards alkali land reclamation in the winter months by pumping from wells and keeping the land flooded. In this way the alkali which is at the surface would be washed into and distributed through the subsoil. This process, of course, would not get rid of the alkali, for it still remains in the subsoil and heavy flooding every few years would be necessary to keep it down.

These are some of the practical suggestions offered for the reclamation of alkali land, but none of them is as feasible and as economical as the method proposed and demonstrated by the Bureau of Soils, and none of them guarantees a permanent reclamation. The only way to permanently rid the Fresno district of alkali and seepage water is by underdrainage.

It was necessary in the reclamation of the Toft-Hansen tract to effect drainage by pumping, but fortunately in the area at large there is no necessity for pumping, since, with the exception of very small areas, all land tributary to the district under consideration can be drained by gravity. While the cost of pumping water has been very much reduced in recent years and pumping plants are being used in irrigation and drainage, the experience gained by the Bureau's field parties and the facts brought out by a study of pumping plants for drainage at home and abroad are strongly opposed to the use of such plants when it is possible, without too great outlay, to carry off the water by gravity. The conditions around Fresno are exceptionally favorable for a gravity system.

Having determined that a gravity system is feasible, the next step is to find out how such a system can best be operated, whether through the use of open or closed drains. Open drains of the proper depth for main, primary, and secondary drains in the Fresno district would have to be dug largely below the level of standing water in what is frequently a quicksand. Such drains, if they are to stand, would have to be boxed in at the bottom and sides and made very wide at the top. The plan has been proposed of placing these drains along the county roads running east and west. There is not always room in these roads to permit a 20-foot ditch being dug without encroaching on private property; hence over more than half the distance a right of way would have to be purchased. The building of bridges and the necessity for annual cleaning are items of expense to be included in the cost of open drains. A comparison of the original cost of open and of tile drains is given below.

The estimates of open drains are based upon prices of similar work in other parts of the country and are, if anything, rather low. The cost of tile draining should vary little from the estimate given.

Cost of open drains per mile.

Ditch 4 feet wide on botton, average depth 7 feet, slope 1 to 1	$2,257.00
Two road bridges at $75 each	150.00
Four farm bridges at $50 each	200.00
Right of way, 1¼ acres at $150 per acre (half the area occupied by ditch)	187.50
Total cost per mile	2,794.50

The cost of the tile drain per mile will vary from $1,000 for 6-inch, to $4,000 for 24-inch tile. The average cost per mile will be about $2,440, a figure below the estimated cost of open ditches. When it is seen that no estimate can be made for boxing the open ditches and when the greater convenience of the tile is considered, it is obvious that the tile are far cheaper and far more desirable.

A detailed study of the conditions existing in the district south of Fresno at present most urgently in need of drainage has developed the following plan, as the one most economical and practical: Parallel lines of tile should be run through the district, following the maximum slope of the ground in a general east and west direction, and at an average distance of one-half mile apart. These lines begin with 6-inch tile, and in the longest lines end with 24-inch tile, all laid at an average depth of 7 feet. The exact location of the lines, whether along the roads or in the fields, will depend largely upon the surface conditions of the soil. No attempt should be made to lay down perfectly straight lines, for slight deviations from an east to west direction will frequently be of great advantage. The tile are laid on a board bed to prevent sinking in the soft subsoil, and at intervals of 500 feet redwood silt boxes are placed with the bottom 1½ feet below the bottom of the tile for the collection of sediment and debris. Each line of tile is supplied with a one-quarter inch galvanized strand-wire rope so that a cleaning brush can be drawn through two or three times a year to remove roots and stir up sediment.

The water from these parallel drains will be collected in an open ditch running in a southwesterly direction just west of West Park. This drainage ditch will have a fall of 1½ to 3 feet per mile throughout its course, dropping where necessary to keep the bottom below the opening of the tile, and will deliver water at the surface of the ground for irrigation south of the Southern Pacific Railroad, between Ormus Station and McMullin.

Such a system could be built for a total cost not to exceed $10 an acre, based upon a district 25,000 acres in extent.

A system of this sort will lower the water table to 5 feet and will not allow it to rise above this level for more than a few days at any one time. With water at 5 feet below the surface the spread of alkali will cease and those lands only slightly damaged will be at once easily reclaimed. Those tracts where alkali is now greatly accumulated it is deemed best to drain with additional lateral tile laid at from 4 to 4½ feet below the surface and 150 feet to 300 feet apart. Laid at a depth of 4 feet and 200 feet apart, such drainage will cost about $16 per acre.

Land so tiled, even if badly alkaline, can be returned to profitable cultivation in six months if heavily irrigated, and within one year can be used for the production of any crop suited to the climate.

As bearing on the cost of tile drainage it may be mentioned that through the efforts of the Bureau of Soils several deposits of good clay have been located within convenient distances of Fresno and that tile-making tests have been carried out. Excellent tile have been made from these clays, and it is hoped that when their manufacture has further developed prices much more in keeping with the cost of production can be obtained on tile, especially when ordered in large quantities. Fuel is cheaper than in the tile-making districts of the east, and the cost of labor is about the same, so there is no reason why tile should not be manufactured and sold at Fresno at very little if any advance, for instance, over the prices asked in Illinois. The foregoing estimates are, however, based upon prices 15 per cent above Illinois prices. We have received assurances from responsible clay workers that if the prices quoted by local firms are not consistent with the value of the article, a tile factory will be built and tile sold at a fair profit.

The drainage system outlined above can reasonably be expected to flow 30 cubic feet of water per second throughout the irrigating season, which, at the present value of water around Fresno, would be worth $15,000. This water will be brought to the surface of the ground in a district southwest of Fresno which only needs water to render it fertile. There is a great deal of alkali land which could be reclaimed with this water and made to produce valuable crops. The drainage water from the Toft-Hansen tract has been repeatedly analyzed to determine its value for irrigation purposes. The following analyses show the composition of the water during three weeks when it was most concentrated·

Chemical analyses of drainage water from the Toft-Hansen reclamation tract.

Constituent.	May 9. Sample No. 9.	May 16. Sample No. 10.	May 23. Sample No. 11.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	3.57	3.58	5.36
Magnesium (Mg)	3.64	3.76	4.28
Sodium (Na)	20.49	19.72	15.47
Potassium (K)	1.58	1.44	1.76
Sulphuric acid (So_4)	2.06	1.88	3.06
Chlorine (Cl)	9.62	9.69	10.73
Bicarbonic acid (HCO_3)	51.82	54.79	59.34
Carbonic acid (CO_3)	7.22	5.14	....
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	2.88	2.63	4.36
Calcium chloride ($CaCl_2$)	7.56	2.63	11.17
Magnesium bicarbonate Mg $(HCO_3)_2$	21.94	22.68	25.89
Potassium chloride (KCl)	3.03	2.76	3.37
Sodium bicarbonate ($NaHCO_3$)	46.17	49.49	52.00
Sodium chloride (NaCl)	5.57	5.59	3.21
Sodium carbonate (Na_2CO_3)	12.86	9.09	....
Total solids in 100,000 parts water	145.4	159.2	130.6

Of the salts shown to be in the drainage water about three-fourths may be regarded as harmful. The remaining 25 per cent are principally salts of lime and magnesium, which would precipitate out by evaporation as the water concentrates upon a field. Sodium carbonate or black alkali, although the predominating salt found in the surface of the soil, is not present in any quantity in the drainage water. Sodium carbonate has never been found in the drainage water as it comes from the tile, but after the water stands and aerates this salt forms by the decomposition of the sodium bicarbonate, so that though we have removed large quantities of black alkali from the soil it has never appeared as such in the drainage water. The explanation of this is that the sodium carbonate or black alkali seldom exists as such except in the first few inches of surface soil, and as soon as it is washed into the soil it absorbs carbonic acid gas, with which the soil air is always more strongly charged than is the atmospheric air, and forms the much less harmful sodium bicarbonate.

Numerous examples can be given where waters of greater concentration than this drainage water are successfully used for irrigation, both in the United States and in other countries, and it can be definitely stated that water of this character can be used for irrigation upon any soil where adequate underdrainage is maintained. If such water were used upon poorly drained soil the inevitable result would be an accumulation of alkali at the surface. The drainage water from the entire alkaline area will not be as concentrated, as that shown in the table above; on the contrary it will be much better for irrigation purposes. These analyses are typical of what might be the maximum quantity of harmful salts, and moreover represent a condition which can exist but a few months at the most, when the drains are first installed.

The reclamation work on the Toft-Hansen tract has progressed so far that the most skeptical must be convinced that drainage and irrigation will reclaim alkali lands. A district of nearly 26,000 acres is now suffering more or less from alkali and seepage water, and it rests with the owners of this land to form a drainage district under the act passed by the last legislature of California, approved March 20, 1903. The formation of this district will allow the construction of a drainage system which will result in the reclamation of all lands now alkaline and the prevention of further damage from this source.

The system recommended, after over three years' study of the conditions, consists of tile drains varying in size from 4 inches to 24 inches. The main drain will be an open ditch collecting the water from the parallel tile drains one-half mile apart. This main will deliver the water at the surface of the ground in the district west of Fresno where it can be used for irrigation. The main tile will be laid in approximately straight lines, increasing in size up to 24 inches in diameter. On the fields badly charged by alkali further drainage by 4-inch, 5-inch, and 6-inch tile laterals may be necessary, but such fields are comparatively few. The cost of this system, calculated on a basis of 20,000 to 26,000 acres, should not exceed $10 per acre. The work of the Bureau of Soils legitimately ends with the demonstration now being completed on the Toft-Hansen tract. The formation of the district and the building of drains and the reclamation of land will rest entirely with the voters and the owners of the land.

THOMAS H. MEANS,
W. H. HEILEMAN.

Approved:
JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *September 1, 1903.*

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United States Department of Agriculture.

BUREAU OF SOILS.—CIRCULAR No. 12.

MILTON WHITNEY, CHIEF OF BUREAU.

[In cooperation with the Utah Agricultural Experiment Station, Prof. J. A. Widtsoe, director.]

U. S. DEPARTMENT OF AGRICULTURE,
Washington, D. C., December 29, 1903.

SIR: In May, 1902, the Bureau of Soils, under your direction and by authority of the Secretary of Agriculture, entered into cooperation with the Utah Experiment Station for the purpose of demonstrating to the people of Utah the practicability of reclaiming alkali land. A tract of 40 acres near Salt Lake City was donated for the purpose by Mr. E. D. Swan, and active steps were taken to underdrain and properly flood this land. The understanding was that the Bureau of Soils should have charge of the actual reclamation work, and the experiment station should have charge of the subsequent work of demonstrating the practicability of growing various crops on what was formerly waste land. This circular, which is a report of progress, shows that the actual reclamation has been nearly accomplished, and the tract will probably be ready in 1904 to be turned over to the experiment station workers, who will then experiment in growing different crops on the soil.

Respectfully,
THOS. H. MEANS,
In Charge of Alkali Reclamation Investigations.

Prof. MILTON WHITNEY,
Chief of the Bureau of Soils.

RECLAMATION OF ALKALI LAND NEAR SALT LAKE CITY, UTAH.

In 1899 a party from the Bureau of Soils, in cooperation with the Utah Experiment Station, made a soil survey[a] of that portion of the Salt Lake Valley lying west of the Jordan River. In this report full and careful consideration was given to the question of the alkali soils around Salt Lake City, the cause of their formation, their character and present extent, and the means of their amelioration and reclamation. The following paragraphs are taken from this report:

> On the west side of the Jordan River the earliest attempts at irrigation were on the Jordan meadows, or river bottom lands, the water supply being obtained from the

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[a] Soil Survey in Salt Lake Valley, Utah, by Frank D. Gardner and John Stewart. Field Operations, Division of Soils, 1899, pp. 78–114. This report was also published as Bul. 72 of the Utah Experiment Station.

Jordan River by means of small canals. Subsequently the Brighton and North Point and the North Jordan canals were run upon the first terrace above the river, and following these were the South Jordan and the Utah and Salt Lake canals on the second and third benches, respectively.

As is frequently the case, the irrigation on the benches caused an accumulation of seepage and alkali on the river bottom land, so that much of it has been abandoned. The largest and most seriously damaged area, however, is just south of Twelfth Street road, and comprises a strip of land varying from half a mile to a mile and a half in width, and extending 10 miles west from the river. Here the seepage and surplus waters from the outer extremities of the Utah and Salt Lake, the South Jordan, and the North Jordan canals have collected to an alarming extent. Indeed, the damage has gone so far that a chain of lakes has formed, presenting a water surface of fully 1,000 acres. The area affected is not less than 10 square miles.

* * * * * * *

The seepage and waste waters from the canals account in great measure for the 10 square miles of good land which has already been ruined by seepage and alkali. It has been shown that the water is of good quality, and the lands of the upper benches are naturally free from any great excess of alkali; but the continual seepage from the canals during the growing season for a great many years has transported a quantity of salt to the lower levels.

The necessity of careful construction of the canals, especially those on gravelly lands, and the desirability of preventing the waste water from flowing over the lower levels is sufficiently obvious without further comment.

The application of water on the lowlands west of Salt Lake City, where there is a large amount of alkali in the lower depths, has been attended with very disastrous results to crops. The salt has quickly risen to the surface and, even where the surface foot was originally free from alkali, the crops have been completely ruined in the course of two or three years.

* * * * * * *

Attention has already been called to the necessity of underdrainage for protection against injury from seepage waters and alkali and for the reclamation of injured lands. Irrigated lands in the Salt Lake Valley are worth at least from $60 to $100 per acre. Land immediately adjacent to Salt Lake City, especially if held as suburban property and if free from alkali, would be worth much more than this. There is plenty of good tile clay in the vicinity of Salt Lake City, and tile could be manufactured for the farmer at a reasonable cost. It is estimated that it would cost from $10 to $20 an acre to underdrain these lands which, under the present conditions have a merely nominal value.

Lands in New York, Ohio, and Illinois, worth from $50 to $75 per acre, have been very extensively underdrained in order to increase their productiveness, to hasten the maturity of the crops, and to insure the crops from injury by drought. It would certainly be a reasonable proposition to protect these valuable lands and to reclaim in the same way what would be valuable land. Money so invested is in the nature of an insurance against loss of crops from seepage waters and alkali.

During the course of this investigation particular attention was given to the possibility of reclaiming the vast tract of 125 square miles between Salt Lake City and the Great Salt Lake. The levels of the railroad surveys and of the canal companies were freely consulted. At Salt Lake City the level of the Jordan River is about 20 feet above the level of the water in the Great Salt Lake. The distance across is about 14 miles. There is a slight ridge, however, running a little west of north about a third of the way across from Salt Lake City. From the crest of this ridge to the Great Salt Lake there is a uniform fall of approximately 3 feet to the mile. This would be ample for the main drainage canals, as the irrigating canals have only about one-half this fall. Furthermore, there are many draws, already 4 to 8 feet

> deep, extending like fingers through this area, which with little additional work could be made to answer for a considerable part of the drainage system.
>
> On account of the impervious nature of the Jordan clay, the great salt content, and the low elevation, it would not be advisable to attempt drainage over this class of land at the present time. Subtracting this area, estimated at 35 square miles, from the 125 square miles, the value of the remaining lands, if thoroughly drained, would be about $3,000,000. At present they have merely a nominal value.

Since the publication of this report no step has been taken by State or county authorities toward any general scheme of drainage and reclamation, and so far as the knowledge of the Bureau goes, no work of any moment has been attempted by individuals.

In order to bring a matter of so much importance to the attention of the farmers, as well as of the community at large, an experiment to demonstrate the value of drainage in alkali reclamation was planned by the Bureau of Soils. In the carrying out of the work the Utah Experiment Station entered into cooperation with the Bureau of Soils, and in 1902 a tract of 40 acres belonging to Mr. E. D. Swan was selected for the demonstration. This tract lies 4 miles west of Salt Lake City, in sec. 5, T. 1 S., R. 1 N., and is about half way between the two railroads running directly west from Salt Lake City to Salt Air and to Garfield Beach. The nearest railroad station is Buenavista, distant one-fourth of a mile from the tract, on the San Pedro, Los Angeles and Salt Lake Railway.

The land, at the time work was commenced, was all strongly impregnated with alkali salts, and had nothing growing upon it except a few alkali weeds, the most prominent of which was greasewood (*Sarcobatus vermiculatus*). The land was considered valueless by the farmers of the neighborhood.

The tract lies on the east side of Williams Lake, and at its highest point has an elevation of about 8 feet above the part of the lake bed adjacent to the tract. The sketch map on page 5 shows the plan of the tract, and the size, depth, and distance apart of the draintile installed.

The cost of this installation was as follows:

270 feet 10-inch tile, at $100 per M feet	$27.00
300 feet 8-inch tile, at $64 per M feet	19.20
520 feet 6-inch tile, at $27.50 per M feet	14.30
6,580 feet 4-inch tile, at $17 per M feet	111.86
2,890 feet 3-inch tile, at $13 per M feet	37.57
Fittings	2.80
Freight on 3 carloads, Ogden to Buenavista	60.00
Cartage and scattering tile	17.50
606 rods ditch, at 50 cents per rod	303.00
67 rods main ditch, at 54 cents per rod	36.30
673 rods covering with team	19.50
150 feet outlet ditch (open)	6.00
One-fifth cost of tools	5.00
Total cost	660.03

The average cost of the drainage system completed was $16.50 per acre, and it is believed that the drainage of larger tracts could be accomplished at about the same cost. Some of the stated items of expense could be considerably reduced, but others would be greater. For example, while it might be possible to obtain better prices on tile, if purchased in larger lots, the drainage of any more extensive area would require the digging of an outlet either to the Jordan River or to Great Salt Lake.

The tract is composed of a surface soil of loam and sandy loam, with a depth ranging from 12 to 18 inches. The underlying material is a heavy clay. A very shallow sand stratum occurs at a depth of 4 feet over the greater part of the tract. The lower, or lakeward, half of the tract is underlain at an average depth of 26 inches by white calcareous hardpan, from 1 to 2 inches in thickness. Occasionally two strata of this hardpan are found, the first lying about 4 inches above the second.

Another special soil feature occurs in places in the tract. This consists of a layer of peculiar brown material, somewhat inclined to fracture along lines after the manner of adobe, and yet maintaining in the interior part of the layer a hard impervious core. This material is found at from 4 to 12 inches beneath the surface. When it is turned with the plow in a dry condition, it breaks into particles ranging in size from inch cubes to granules about as large as buckshot. When wet, it still breaks on regular lines of fracture, but materially softens, and if thoroughly plowed loses its hardpan properties. In excavating during the drainage installation it was necessary to break the dry material with a pick, as was also the case with the white hardpan.

With the above soil and hardpan conditions it was deemed advisable to place the drains 150 feet apart, and this interval was used, except in one instance. The system for the 40 acres includes eight lateral drains and one main drain. Each of the laterals is 1,250 feet long, and is laid with 850 feet of 4-inch and 400 feet of 3-inch draintile. The exception already referred to is in the interval for lateral No. 8, which is laid 200 feet from the nearest lateral, the object being to study its efficiency under such conditions of soil as exist in this tract.

The main drain is put in across the lower part of the tract, 20 feet from its west side, and is met by seven of the laterals. This drain was laid with 270 feet of 10-inch, 300 feet of 8-inch, and 520 feet of 6-inch tile.

The 10-inch tile in the main drain have a capacity sufficient to remove 4 inches of water per week from the adjacent lands, or lands underlain by laterals Nos. 1 to 7. Ordinary operations for reclamation do not overload the drains, however, since the factors of summer evaporation and subdrainage through the soil play important parts in the disposal of the water added in flooding operations.

Over the great part of the tract the drains were laid at a depth of 4 feet. In that part nearer the lake a somewhat shallower depth was necessitated in order to obtain a gravity outlet for the drainage water. The drains were laid on a grade of not less than one-tenth foot in 100 feet, except where 3-inch tile was used when the grade was somewhat higher. The illustration (fig. 1), is a plan of the completed system, and shows the supply canals, position of the weirs, drains, and the position and extent of the different sizes of tiles. The system as installed has proven adequate. Flooding has been carried on systematically, the land being divided into checks and plats by levees, and each plat treated in rotation. During each flooding water has been added to an average depth of 4 inches. The movement of the water into the soil has been regular, and, considering the character of the clay subsoil, rapid, and the drains have quickly filled after the floodings and have run freely throughout the experiment.

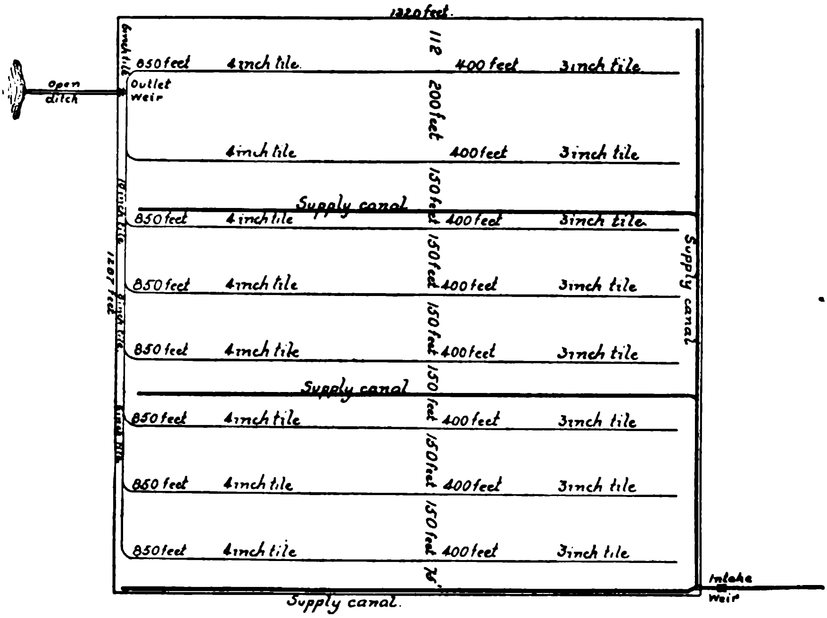

FIG. 1.—Plan of drainage system, Swan tract.

During the last season (1903) the land was flooded once each week, with occasional longer intervals when the supply canal was being repaired or during times when the land was being plowed or the levees repaired.

Before any water was applied to the tract a detailed survey was made to determine the alkali content of the soil. This initial survey was made in September, 1902. The land was then flooded once and allowed to remain until the next spring.

In May, 1903, before work was commenced, a second survey was made; and a third survey of the tract was made in October, 1903, after the close of the season's operations.

The following table gives the tonnage of alkali in the tract, as shown by these surveys:

Quantity of alkali in the first 4 feet of soil in the Swan tract, Salt Lake City.

Soil sections.	September, 1902.		May, 1903.			October, 1903.		
	Alkali in 40 acres.	Per cent of total.	Alkali in 40 acres.	Per cent of total.	Per cent lost.[a]	Alkali in 40 acres.	Per cent of total.	Per cent lost.[a]
	Tons.		*Tons.*			*Tons.*		
In first foot	1,363	20	499	14	63	101	8	92
In second foot	1,540	23	650	19	58	183	15	88
In third foot	1,766	27	1,066	31	40	330	28	82
In fourth foot	1,982	30	1,265	36	36	607	49	69
Total	6,651	....	3,480	....	49	1,221	....	82

[a] Shows the proportion of the salts removed as compared with the salt originally present in the various depths.

The data given in the above table shows that between September, 1902, and the following May, 3,171 tons of salt had been removed from the soil to a depth of 4 feet, and that between September, 1902, and the following October, 5,430 tons had been removed, or 82 per cent of the alkali originally in the first 4 feet of soil. It is also seen that a greater proportion of the alkali has been washed out of the surface foot than out of the lower depths, and that the movement of the salts is less pronounced as the depth increases. Thus originally the fourth foot carried 30 per cent of the total salt, while in October, 1903, the fourth foot carried 49 per cent of the salt then remaining in the soil. There has been, however, a marked decrease in the quantity of salt at all the depths, and the fourth foot has in reality lost 69 per cent of the quantity of alkali originally present.

It must be understood that these changes have taken place through the movement of the salts downward by percolating water and not through washing them from the surface of the land.

The following table shows the number of acres of land in each of the six grades into which the Bureau classifies alkali lands, for the various depths to which determinations were made in the tract. The table gives the area in each grade in September, 1902, and the area in each grade in October, 1903, after one year's operations in the reclamation work.

Areas of land of different grades of alkali, September, 1902, and October, 1903.

Alkali present in soil. (Grade.)	First foot.		Second foot.		Third foot.		Fourth foot.		All four feet.	
	Sept., 1902.	Oct., 1903.	Sept., 1902.	Oct., 1903.	Sept., 1902.	Oct., 1903.	Sept., 1902.	Oct., 1903.	Sept., 1902.	Oct., 1903.
	Acres.	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*
0 to 0.20 per cent...	None.	35.6	None.	21.4	None.	6.7	None.	1.0	None.	16.2
0.20 to 0.40 per cent.	3.0	1.6	.4	11.0	.1	16.8	.1	15.0	.9	11.0
0.40 to 0.60 per cent.	3.3	1.1	2.3	4.5	.7	8.8	1.3	5.4	1.9	5.0
0.60 to 1 per cent...	10.7	.5	8.0	1.5	3.9	4.5	6.2	8.1	7.2	3.6
1 to 3 per cent......	16.8	None.	19.7	.4	22.6	2.0	18.1	9.3	19.3	3.0
Over 3 per cent	5.0	None.	8.4	None.	11.5	None.	13.1	None.	9.5	None.

The above table shows clearly the increase in the acreage of soils containing a low percentage of alkali; the columns headed September, 1902, showing the original condition of the tract, and those headed October showing the condition at the time of the last examination.

The following table shows the volume of water added to the tract from September, 1902, until October, 1903. The table shows also the volume of drainage over the outlet weir, and the salts (alkali) removed from the tract in the drainage water. The results are obtained from continuous measurements and daily collections of water samples for the entire period.

Total quantity of water used in flooding the tract, quantity flowing off through drains, and quantity of salts removed in drainage water.

Month.	Volume of water added to tract.	Volume of drainage water from tract.	Salts in drainage water.
	Cubic feet.	*Cubic feet.*	*Pounds.*
1902—September........	284,400	158,700	152,200
October........	940,000	265,000	195,100
November........	[a] 171,300	251,000	353,800
December........	[a] 166,500	139,700	187,800
1903—January........	[a] 291,800	257,300	391,200
February........	[a] 136,400	174,400	214,800
March........	[a] 132,000	428,000	590,700
April........	[a] 112,000	26,900	26,500
May........	[a] 576,900 760,900	521,500	567,100
June........	[a] 106,000 676,500	274,500	345,200
July........	[a] 36,580 1,691,970	480,490	556,459
August........	2,122,160	814,890	1,221,742
September........	2,352,920	1,195,976	1,654,115
October........	351,290	663,420	840,981
Total........	10,909,620	5,651,776	7,297,697

[a] Fell as rain or snow.

Total volume of canal water used........	cubic feet..	9,180,140
Volume falling as rain and snow........	do....	1,729,480
Total volume from above sources........	do....	10,909,620
Total water used........	acre feet..	250.4
Salts added in the canal water........	pounds..	900,000

The total volume of drainage was 5,651,776 cubic feet, or 51.8 per cent of the water added to the tract. This 51.8 per cent drainage water carried 3,648 tons of salts over the outlet weir. The remainder of the salts removed from the tract have passed into the deeper subsoil and been carried away by the natural subdrainage.

The results so far obtained indicate the ultimate complete reclamation of the land. The single season's operations produced marked improvement in the land, not only in the alkali content, as shown by the soil tests made, or as shown by the salts in the drainage, but also as shown in the improved tilth of the soil and the favorable changes that have taken place in its physical properties.

The indications are that the greater part of the tract is at present sufficiently sweetened to allow the growing of shallow-rooted crops. It is the intention to continue the work until reclamation is complete, and the data pertaining to the process of flooding and drainage will be supplemented by practical crop tests during the season of 1904.

W. H. HEILEMAN.

Approved.
JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *February 2, 1904.*

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S. 22.

U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 88.

ALKALI LANDS.

BY

MILTON WHITNEY AND THOMAS H. MEANS.

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U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., January 4, 1899.

SIR: The interest taken in the alkali work of this division in Montana during the summer of 1898 has been so widespread, and there have been so many requests for copies of a technical bulletin upon the subject, which is just about to be issued, that it has been thought proper to present the matter in a rather more popular style, leaving out some of the technical descriptions and the expensive illustrations, in order that it may have very wide circulation. This material, while almost entirely rewritten, is essentially the same as that contained in Bulletin No. 14 of this division.

I recommend that this be published as a Farmers' Bulletin.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

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ALKALI LANDS.

INTRODUCTION.

Alkali and the treatment of alkali soils are subjects which are attracting very great attention at the present time, as alkali has already injured or is a serious menace to large areas of land. It is encountered in all arid districts the world over. It is always a source of uneasiness in such sections, for if the alkali is not apparent when the lands are first irrigated it is liable to appear after a few years as a result of the present system of irrigation. The uncertainty itself, and the serious nature of the trouble, calls for most energetic measures for the prevention of injury and the reclamation of ruined lands. Lands which a few years ago showed no signs of alkali, but, on the contrary, were extremely fertile, and upon which large amounts of money have been expended in farm improvements, are now, after ten, fifteen, or twenty years, being ruined by an accumulation of seepage waters and of soluble salts.

It is not intended at this time to undertake a general discussion of the alkali problem, as it will require many years of constant work to obtain an accurate knowledge of the conditions over the arid regions of this country. But the results of some investigations carried on during the summer of 1898 in the Yellowstone Valley are so important and of such widespread practical application and value that they are published in this form to help stimulate an interest in the subject, and to show, under certain conditions at any rate, that the means for the prevention of the rise of alkali and for the reclamation of alkali lands are well within the power of the farmer.

In taking up the study of the alkali problem the division was fortunate in selecting the Yellowstone Valley, where the conditions are as simple as can be found anywhere. There are many other areas in this country where the conditions are quite as simple, and where the matter can be brought under just such control as there, while there are much more difficult problems in other sections, due to location and topography of land, to the small available water resources, to the texture of the soil, and to the kind and distribution of the alkali.

THE CONDITIONS IN THE YELLOWSTONE VALLEY.

The investigations were carried on near Billings, Mont. At this place the Yellowstone Valley is from 6 to 10 miles wide. The valley is about 400 miles long in Montana, and irrigation is spreading from a number of centers within this area.

Irrigation has been practiced at Billings for the past twelve or fifteen years. The water for the main irrigation canal, supplying the valley at this place, is taken out of the Yellowstone River nearly 40 miles above the town of Billings. When the country was first settled (and, indeed, at the present time, in the area above the ditch) the depth to standing water in the wells was from 20 to 50 feet, and there were no signs of alkali on the surface of the ground. Under the common practice of irrigation, however, an excessive amount of water has been applied to the land, and seepage waters have accumulated in the soil to such an extent that water is now commonly found in wells throughout the irrigated district at a depth of from 3 to 10 feet from the surface. Many large tracts of once fertile lands on the lower levels are already flooded, and alkali has accumulated on them to such an extent that they are mere bogs, swamps, or alkali flats. This injury, while not very widespread as yet, has been so serious where the results have appeared, and the future is so uncertain that the owners of the land are naturally very much concerned. This is but too common a history of many large and fertile areas in Utah, in southern California, in Colorado, and, in fact, in nearly all of the older irrigated districts.

The valley at Billings is bounded on the north side by a sandy bluff of gray siliceous stone rising abruptly to a height of from 200 to 500 feet above the general level of the valley. On the south side there are steep, ragged hills of blue slate or shale. This shale dips down and passes under the sandstone bluffs about on a level with the present surface of the valley. The valley lands have been formed by the disintegration of both the sandstone and shale. In places the sandstone has been entirely worn away, leaving the soil formed from the disintegration of the shale exposed in places throughout the valley. This soil is stiff gumbo. The shale is very deep, borings for an artesian well having been made to a depth of 900 feet, and through the whole depth this shale has been found. In other parts of the valley the sandstone has not been so completely removed, and there are large areas of sandy or loam soils with the gumbo subsoil at a considerable depth below the surface. These areas are recognized as sandy soils, while the others are classed as gumbo. There are mixtures, of course, grading from one to the other, and these mixed soils are the most abundant in the valley.

Both the sandstone and the shale rocks contain large quantities of soluble salts, which are seen as shining crystals throughout the mass. The shale, however, contains very much more than the sandstone.

As the rocks have disintegrated through the influence of the weather the minerals have been broken down into simple mineral salts that have remained as soluble salts in the soil. The reason for this accumulation is the small annual rainfall occurring in the arid regions. It is so little and the drainage is so slight that the salts accumulating from the disintegration of the rocks are not carried off into the ocean, as is the case in the soils of the humid regions. In the Eastern States, with an annual rainfall of 40 inches, nearly half of this leaches down through the subsoil and eventually finds its way through the streams and rivers into the ocean. This carries with it the greater portion of the soluble salts, as they are set free in the disintegration of the rocks. With less than 10 inches of rainfall, as occurring in the arid portion of the United States, the drainage is extremely small, and there is no natural means provided, therefore, for removing the salts as they are formed. This accumulation explains at once the wonderful fertility of the lands generally in the arid regions the world over, but it is also a constant menace because of the large amount of soluble salts which is liable to accumulate locally as the result of irrigation or as a result of other natural conditions not well understood, until they are a menace and often a destructive agency for the very lands which were formerly held in such esteem.

In the formation of the valley soils at Billings from the decomposition of the sedimentary rocks undoubtedly part of the soluble salts have been removed. Furthermore, as the drainage through the sandy soils is much freer than through the gumbo, and as there is less salt to start with in the sandstone rock than in the shale, it is natural to suppose that there is less of the soluble salts in the sandy soils of the valley at the present time than in the gumbo soils, and this is a fact proved by the investigations.

The alkali soils of the West are of two principal classes: The alkaline carbonates or black alkali (usually sodium carbonate) is the worst form, actually dissolving the organic materials of the soil and corroding and killing the germinating seed or roots of plants; the white alkalies, the most common of which are sodium sulphate, sodium chloride, magnesium sulphate, and magnesium chloride, are not in themselves poisonous to plants, nor do they attack the substance of the plant roots, but are injurious when, owing to their presence in excessive amounts, they prevent the plants from taking up their needed food and water supply.

The amount of soluble salts which plants can stand depends upon the character of the salt, the character of the soil, and the kind of plant. Hilgard states that few plants can stand as much as 0.1 of 1 per cent of sodium carbonate, or about 3,500 pounds per acre to a depth of 1 foot; of sodium chloride plants can stand about 0.25 of 1 per cent, and of sodium sulphate 0.45 to 0.50 of 1 per cent. Plants can stand less salts in sandy lands than on heavy clay or gumbo lands. It is a well-known fact that crops also differ in their ability to stand salts, and many crops will grow well upon soils on which others will not live.

Dr. F. W. Traphagen, of the Montana Experiment Station, finds that the composition of the salt appears to be quite uniform throughout that portion of the valley which was examined around Billings. The following table gives the mean of five analyses which he made:

Composition of the soluble salts at Billings, Mont.

	Per cent.
Sodium sulphate	57.44
Magnesium sulphate	27.59
Calcium sulphate	13.05
Potash sulphate	1.55
Silica	.36
Total	99.99

The soluble salts at Billings are thus seen to be mainly sodium sulphate and magnesium sulphate, with none of the destructive sodium carbonate. There is but a trace, likewise, of sodium chloride. The soils all abound with calcium sulphate or gypsum.

It has been found that the solid grains of soil have the remarkable power of absorbing or concentrating a portion of the salts on their surface and thus withdrawing them from active solution. This is of the greatest practical importance, as otherwise the soil moisture would quickly become saturated with salts and rendered totally unfit for agricultural plants. As a matter of fact, in consequence of this condensing power, in no case was the concentration of the soil moisture found to exceed 3 per cent, although the salts were quite soluble and were crystallized out on the surface of the ground.

The investigations at Billings showed that when the concentration of the salts in active solution in the soil moisture is as great as 1 per cent the limit of most cultivated plants is reached. Further concentration kills all our ordinary agricultural crops. It was found, furthermore, that plants could just exist with 0.45 of 1 per cent of the soluble salts present, equivalent to about 15,000 pounds per acre-foot, and this is taken as the limit of plant production. The soluble salt content of soils in the humid portion of the United States ranges from 50 pounds per acre-foot in the sandy soils of the Atlantic coast to as much as 3,000 or 4,000 pounds in some of the heavier agricultural soils. The average amount would be considerably less than 1,000 pounds per acre-foot.

THE RAINFALL AND SEEPAGE.

There are no available records of the amount of rainfall at Billings, but at Miles City, about 130 miles northeast, the Weather Bureau records show an average annual rainfall of 12.8 inches. From May to September, inclusive, there are 6.7 inches, and during July and August 1.3 inches.

When the rains occur in the spring and wet the surface of the ranges, vegetation flourishes in the most luxuriant way and the grasses give very good grazing. The rains, however, appear to be only sufficient to wet the surface to a very slight depth; the water is quickly used up, and true desert conditions prevail during the summer time.

It appears that in the dry season the soil is moist from 3 feet down, but so slightly moist and the depth of the dry material is so great that it is altogether unlikely that the spring rains pass down to any appreciable extent locally in any one year. The conditions, therefore, are unfavorable to a natural leaching of these soluble salts, except through the exceedingly slow movement there may be in the slightly moist subsoil.

HOW THE SALT DETERMINATIONS ARE MADE.

In the investigations of the conditions at Billings samples were taken with a long extension auger, and salt determinations were made for every foot in depth down to a depth, often, of 10 or 15 feet. The salt was determined by the electrical method, which has been described in previous bulletins of this division. The instruments used in this method are exceedingly sensitive, and determinations made by them are so very rapid that a large number of samples may be examined in the field. Examinations were made in the different types of soil, that is, in the sandy lands, in the stiff gumbo soils, and in the various intermediate grades that were found. Then several lines of borings were made above and below the irrigating canal and from the alkali flats back to the good lands in order to get an idea of the relation of the texture of the soil and the position of the irrigating canal to the alkali problem. Finally a very detailed examination was made of a section of land containing an alkali flat, and maps were constructed showing the distribution of the seepage waters and soluble salts at various levels under the surface of the ground. The value of such underground maps can hardly be overestimated. It is seen just where the seepage waters and the soluble salts are accumulating, from which direction they are coming, and just how drainage systems should be introduced to remove the trouble. They show which areas are safe for a number of years, those which will need careful attention to prevent the accumulation of salts, and those which need energetic measures for the reclamation of lands already damaged.

THE KINDS OF SOILS IN THE VALLEY.

The following table gives the mechanical analyses of a number of soils from Billings which indicate the difference in the texture of the soils which has been noticed.

Mechanical analyses of soils.

No.	Locality. (Miles from Billings.)	Description.	Moisture in air-dry sample.	Organic matter.	Gravel. (2 to 1 mm.)	Coarse sand. (1 to 0.5 mm.)	Medium sand. (0.5 to 0.25 mm.)	Fine sand. (0.25 to 0.1 mm.)	Very fine sand. (0.1 to 0.05 mm.)	Silt. (0.05 to 0.01 mm.)	Fine silt. (0.01 to 0.005 mm.)	Clay. (0.005 to 0.0001 mm.)
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
3756	2½ N	Sandstone bluff soil.	1.22	2.66	0.00	0.00	0.17	29.39	52.34	3.29	0.88	9.65
3322	11 W	Silty type, creek soil.	2.98	4.40	0.00	0.00	0.16	7.96	28.79	34.45	4.67	17.25
3309	5½ W	Sandy gumbo	1.56	4.66	0.00	0.00	0.20	11.72	45.05	14.69	3.49	19.90
3308	5½ W	do	1.94	3.30	0.00	0.10	0.46	15.61	39.59	14.63	3.38	21.30
3307	5½ W	do	2.35	3.72	0.00	0.02	0.32	21.37	38.27	8.99	3.13	22.55
3306	3 W	Gumbo	3.20	3.30	0.01	0.40	1.58	20.40	27.67	11.71	4.02	27.80
3769	5 W	Heavy gumbo	3.74	4.22	0.04	0.03	0.19	11.65	24.03	15.13	4.40	35.55

The first sample is a very pure type of sandstone soil taken from the top of the bluff about 2½ miles north of Billings and was derived from the decomposition of the soft layers of fine sandstone which cap the bluffs. These soils are very light and loose and have very free underdrainage. As a matter of fact they leach readily and, although they afford the best possible conditions for irrigation in that seepage waters are not likely to accumulate in them, it is probable that they would not last very long, as the soluble salts would easily and quickly be removed from them. Soils of this type are found in many parts of the valley, and there is little or no danger from seepage waters or from an accumulation of soluble salts at the surface, although they contain considerable quantities of such salts at depths below the surface.

The other samples in the table are seen to grade up through the mixed sandy gumbo to the pure form of gumbo with from 27 to 35 per cent of clay. The mixed soils are the most abundant in the valley.

SALT CONTENT OF THE SOIL.

Salt determinations made in the sandy type of soil above the ditch, where irrigation had never been practiced, and below the ditch, where irrigation had been carried on for ten or twelve years, showed that there was no excessive accumulation of soluble salts, but, on the contrary, that irrigation had really leached part of the salts out of the soil.

The following table gives the results of the salt determinations in a number of places in the sandy soil both above and below the ditch:

Soluble salt content in sandy land.

Depth (feet).	Unirrigated.				Irrigated.					
	Boring 62.		Boring 64.		Boring 26.		Boring 27.		Boring 28.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0- 1	0.033	1,155	0.042	1,470	0.046	1,610	0.038	1,330	0.033	1,155
1- 2	.019	665	.041	1,435	.049	1,715	.045	1,575	.037	1,295
2- 3	.045	1,575	.035	1,225	.052	1,820	.044	1,540	.028	980
3- 4	.027	945	.038	1,330	.066	2,310	.051	1,785	.030	1.050
4- 5	.032	1,120	.045	1,575	.097	3,395	.060	2,100	.048	1,680
5- 6	.028	980	.055	1,925	.106	3,710	.051	1,785	.048	1,680
6- 7	.019	665	.056	1,960	.128	4,480	.064	2,240	.048	1,680
7- 8	....	....	.170	5,950	.147	5,145	.070	2,450	.047	1,645
8- 9	....	....	.238	8,330	.112	3,920	.049	1,715	.047	1,645
9-10	....	....	.243	8,505	.112	3,920	.049	1,715	.047	1,645
10-11	....	....	.205	7,175	.056	1,960	.072	2,520	.044	1,540
11-12	....	....	.120	4,200	.056	1,960	.072	2,520	.044	1.540
12-13	....	....	.163	5,705	.058	2,030	.072	2,520	.044	1,540
13-14	....	....	.228	7,980	.058	2,030	.072	2,520	.044	1.540
14-15	....	....	.178	6,230	.058	2,030	.072	2,520	....	....

The limit of excess of alkali in soils at Billings, as already stated, was found to be about 0.45 of 1 per cent. This is equivalent to about 15,000 pounds per acre 1 foot deep. It will be seen from the table that there is not sufficient soluble matter to a depth of 15 feet in this sandy soil to prevent the growth of agricultural plants. It is interesting to note that the amount of soluble salt in the upper 7 feet of the unirrigated soil is particularly small; there is 50 per cent more, perhaps, than is ordinarily found in the soils of the humid region. Below a depth of 7 feet, however, the amount of salt is considerably increased. It would appear that there were evidences here of a slow downward movement of soil moisture, and that under these constant conditions of slow seepage the amount of salt in the upper layers of the soil was constantly diminishing. No examinations could readily be made of the soil below a depth of 15 feet, as this was the extreme length of the auger, but from information furnished by some well-diggers thoroughly familiar with the locality it was learned that the soluble salt content in wells above the canal increases below this to very large proportions. White layers, strongly impregnated with salts, are said to be found below this depth. The water from the wells contains too much of the salts to be of use for domestic purposes, although it is not so strong as to be harmful to cattle.

It is quite reasonable to suppose that the soluble salts had originally been uniformly distributed throughout the upper layers of these soils and that from storm waters and the slow seepage of the slight amount of moisture which the subsoil contains the soluble material had been washed down from the upper layers. Certain it is that similar results follow from the first effect of irrigation where there is good underdrainage, as generally prevails in this sandy soil. In the irrigated sandy land the amount of soluble matter, even to a depth of 15 feet, is comparatively small and the amount throughout the whole depth is quite uniform. This indicates very strongly that the salts have been leached out of the soil and carried off in the underground drainage waters. The examination of the water in a well situated in this irrigated area of the sandy land gives additional proof that some of the salts have been removed. There is a well at the southwest corner of sec. 2, T. 1 S., R. 25 E., near boring 44, in which the water contains 0.119 of 1 per cent of soluble matter, or 60 grains per gallon. Other wells throughout the irrigated area frequently contain as much as 0.4 of 1 per cent of salts.

The heavier type of soil—that is, the gumbo soil—was shown to be derived from the disintegration of the shale. The still undecomposed shale in the bluffs on the south side of the valley was found to be penetrated in every direction with veins of gypsum and the soft shale itself to be permeated with large quantities of sodium and magnesium sulphates. The soils resulting from the disintegration of the shale form a heavy, sticky, blue clay, quite impervious to water. The drainage is so slow through this fine, impervious material that large quantities of the salts remain in the soil.

On account of the poor drainage and the slow movement of the subsoil waters through this material there is great danger of overirrigation, and the problem of irrigation, which is easy on the well-drained, sandy lands, becomes far more complicated and much more difficult to manage on these heavy gumbo soils. Great care has to be taken not only in the application of water, but in the actual cultivation of these soils, as they are liable to be ruined, for a time at least, for alfalfa. On account of the large water content, the fineness of the particles. and the amount of salts these soils contain they easily puddle and get still more impervious to water, and if they are worked when too wet clods form, and it is very difficult to reduce the field again to a good tilth.

On account of these properties the heavier or gumbo soils have to be farmed with very great care. Not only so, but there is great danger from seepage waters from neighboring plantations on higher levels. The soils themselves are naturally extremely fertile and very strong, and last very well if properly cared for. The following table gives the results of salt determinations in typical gumbo soil above the ditch, which has never been irrigated:

Salt content of a heavy unirrigated gumbo soil.

Depth (feet).	Per cent of salt.	Pounds per acre-foot.
0–1	0.035	1,225
1–2	.038	1,330
2–3	.054	1,890
3–4	.200	7,000
4–5	.333	11,655
5–6	.337	11,795
6–7	.253	8,855
7–8	.253	8,855
8–9	.282	9,870

It is apparent from the table that there is a considerable quantity of salt at a depth of 5 feet, and from there down. This boring, with others, is illustrated graphically in fig. 1.

When water is applied to the gumbo soil in the practice of irrigation, the first effect, as in the case of sandy land, is to reduce the amount of soluble salts in the upper layers of the soil. If there is good drainage, this excess of salt may be removed altogether from the soil. If the drainage through the gumbo is slow and inefficient, or, in the case of the sandy land, when underlaid with a compact gumbo subsoil where the drainage is poor, then, in the case of overirrigation, seepage waters will collect, owing to the inability of the soil to remove the water as fast as the excessive quantities are applied.

The following table gives the salt content from several places in one of the alkali flats so formed:

Salt determinations in an alkali flat.

Depth (feet).	Boring 36.		Boring 49.		Boring 52.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0–1	0.757	24,710	0.792	27,720	0.229	8,015
1–2	.714	34,570	.920	32,200	.191	6,685
2–3	.634	21,105	.944	33,040	.182	6,370
3–4	.612	21,035	.792	27,720	.175	6,125
4–5	.589	20,965	.519	18,165	.159	5,565
5–6	.187	6,650	.519	18,165	.213	7,455
6–7	....	....	.357	12,495	....	....
7–8	....	....	.357	12,495	....	....
8–9	....	....	.292	10,220	....	....

It will be seen that in boring 36 the salt has accumulated to enormous proportions in the top 5 feet of the soil. The conditions show that the solution is so strong that a white crust is formed over the surface. However, on account of the absorptive powers of the soil, the solution immediately under this crust and in contact with the soil was only 3 per cent, notwithstanding the fact that the salt ordinarily is very soluble in water. This strength solution, however, is entirely too strong for any cultivated crop, and the alkali flat presented a very desolate appearance.

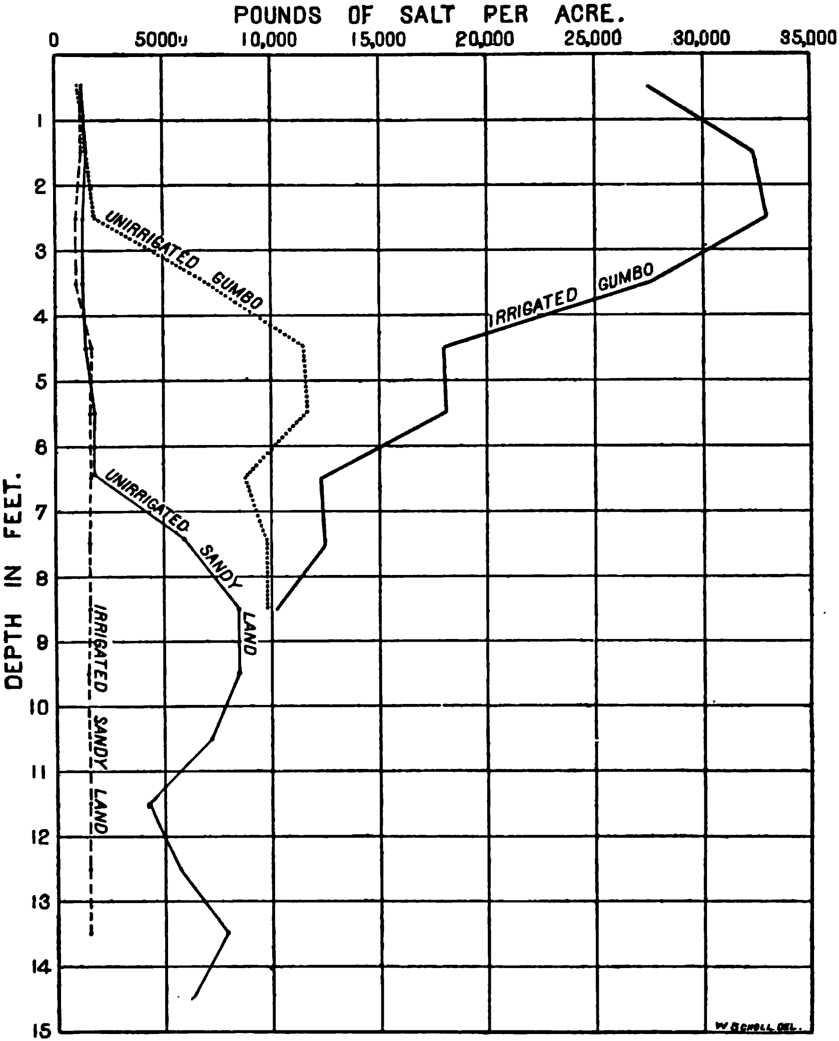

Fig. 1.—The salt content of sandy land and gumbo, with and without irrigation.

In boring 49, which was in the midst of the alkali flat, there was an excessive accumulation of alkali, beyond the limit of any agricultural plant, at least to a depth of 7 or 8 feet. Below this it rather looks as though the amount of salts was diminishing and that if the boring could have been carried deeper the salt content would perhaps have grown less. At the present time the soil in boring 52 does not contain an excessive amount of alkali for alfalfa, but the level of standing water is so near the surface that the roots of the plants are submerged and the crop can not be successfully grown. This is the first stage in the ruin and devastation that is being wrought, and boring 49 shows the final and complete stage when the land is given up to water and alkali.

When land is in the condition of boring 52, and before any notable accumulation of crust has appeared upon the surface, the land becomes covered with a heavy growth of weeds. All agricultural crops have ceased to grow for some time, and the land has been abandoned as a barren waste. Such a condition as is shown by the growth of weeds is usually thought to mean that the alkali is disappearing or is being used up by the weeds themselves, and that the soil is again becoming fit for crops. In some cases this may be true, if there is sufficient drainage to carry off the excess of seepage waters and time enough be allowed for them to move on; but in many cases the conditions simply indicate that the weeds are a class of plants which can thrive on wet ground and grow for a while luxuriantly. If the methods of irrigation are kept up and the seepage waters continue to collect and evaporate for a few years longer, alkali will accumulate in sufficient quantities to kill even the growth of weeds, and the land will truly present the appearance of a desert.

From all the facts thus far observed it can be said that the first harmful effect of overirrigation in these soils is caused by excess of water, and if this is not immediately removed further damage will result from the accumulation of soluble salts. If the excess of water is soon removed no permanent damage will result.

A line of borings was run from the center of this alkali flat for a mile and a half back to the main canal. A number of borings were made to a considerable depth and salt determinations made for every foot in depth in each of these borings. It was found that adjoining the canal and for two-thirds of the way down to the alkali flat there is but little alkali, as though the irrigation water had removed the salts from this portion of the land and that they had then accumulated in the alkali flat, which is at a somewhat lower level. These irrigation waters slowly seep through the underground channels down into the natural drainage system, which is represented in this case by the alkali flat on account of its somewhat depressed condition. The water first appears in these low places in the line of underdrainage, and as the evaporation of the water goes on the salts accumulate, gradually extending up and enlarging the alkali flats as the water rises until the level of the surrounding area is reached, when the whole district is abandoned. The area around the alkali flat is first-class alfalfa land

and the property is considered very valuable, but only three or four years ago the alkali flat itself was considered just as valuable, and the alarming feature of the whole thing is that the owners know that if these conditions continue the alfalfa field itself will be ruined and will have to be abandoned in a few years unless very energetic means are taken to arrest the progress of the trouble.

The chances are, of course, that this condition has not arisen from the local application of water at this place. It is possibly a result of injudicious methods of irrigation on the adjoining lands at higher levels. One of the most discouraging features of the whole problem is that the owner of such a tract of land may use the most approved methods of irrigation and yet be completely ruined by the excessive and injudicious use of water by his neighbor. This neighbor may escape the injurious effects of his own crude methods, at least for many years after the other has been ruined. In the contemplation of such a problem as is presented in the Yellowstone Valley, therefore, there are certain property rights that may easily be abused, causing very disastrous results to appear upon a neighbor's land. It makes the whole problem very hard to deal with, especially as it would be extremely difficult to show the source of the trouble and to locate the offending person. It is a problem, however, which will have to be taken up; and if the property owners do not themselves take adequate care of their drainage systems and use intelligent methods of irrigation some means must be found of compelling them to do so or to give redress to their unfortunate neighbors.

This accumulation of salts is very harmful in the puddling effect on the soil. The flocculation of the soil grains is broken up and the grains are separated out into their most uniform position, where they offer the greatest possible resistance to the flow of water. This puddling can be relieved only by draining off the water and the salts, and this drainage is rendered difficult by their presence, so that the reclamation of these alkali flats on the gumbo soil is an exceedingly difficult, slow, and expensive undertaking.

The formation of these alkali flats is in a way an evidence of the effort of nature to correct the faults of our crude system of irrigation. The salts are being carried off into the natural drainage of the country, but the process is very slow and the excess of seepage water and the salts themselves collect in these places on account of the inability of the soil to let them pass as rapidly as the excess of water is supplied. This suggests the only feasible method of reclaiming these lands and, indeed, of preventing the accumulation of the salts which will occur except under the most careful and judicious methods of applying water. In cases like that under consideration, where the damage has already been done, the natural drainage is so slow that it does not afford adequate relief, and in fact is but a sign of impending ruin for a very much larger area. The only way to reclaim the land is to put in an efficient system of drains, preferably of underground tile drains. It is urged against this idea that the land is not worth the cost of the investment in putting in a system of tile drains. This, of course, is an economic problem which is entirely dependent upon conditions of market, transportation facilities, and other commercial considerations. It may or may not be profitable at this time to protect the lands from destruction and to reclaim those that have been destroyed. It may be cheaper to move off into new areas, but the time will come, if it has not already come, when the land in the Yellowstone Valley and in similar situations will be worth the care and expense necessary to protect it from ultimate destruction. The amount of money now invested in the Yellowstone Valley is enormous, and the continuance of prosperity is entirely dependent upon the care which is taken in the methods of irrigating the lands. Property worth thousands of dollars may be ruined in a few years and become utterly worthless. The experience in the valley shows that this has been the case in the past, and there is much uneasiness felt in regard to large areas which show signs of the rapid spread of alkali.

EFFECT OF UNDERDRAINAGE IN REMOVING SALT.

There is abundant evidence that thorough underdrainage will reclaim these lands, and if introduced in time will prevent any such disastrous results as those which have been described. There has been no thorough system of tile drainage tried, but a few efforts have been made to reclaim the abandoned lands by open drains. That these have been efficacious the following investigations will show:

A drainage ditch had been dug in the alkali flat on section 2, T. 1 S., R. 25 E., and the excess of water had been continuously removed for some time before this investigation was made. A line of borings was made from this ditch back about one-fourth mile to see how the salt content had been changed. The results are given in the accompanying table, which represents the per cent of soluble salt found at different distances from this ditch.

Salt determinations at different distances from a drainage ditch.

Depth (feet).	Boring 45.	Boring 46.	Boring 47.	Boring 48.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0–1	0.047	0.054	0.155	0.419
1–2	.030	.066	.164	.253
2–3	.036	.112	.177	.257
3–4	.031	.103	.213	.238
4–5	.045	.109	.191	.275
5–6	.045	.120	.191	.267
6–7	.043	.138	.225	.275
7–8	.043	.162	.237	.337
Average	.040	.108	.194	.290
Total pounds per acre 8 feet deep.	11,200	30,280	54,320	81,200

Boring 46 shows the amount of salt about 300 yards from the drainage ditch. The next column shows the amount at about 100 yards from the ditch, while the last column shows the amount closely adjoining the ditch. It will be seen from this table how the salts have accumulated at the lowest point of the drainage system and how they are being removed by the drain as the water from the irrigating ditch seeps down and the excess of seepage water is carried off. The amount of salt found at the drainage ditch is already below the 15,000 pounds limit of crop production, while farther out in the alkali flat, under presumably the same conditions as existed at the drainage ditch when it was cut, the amount of salt is upward of 35,000 pounds per acre-foot.

It is easy to show in another way the beneficial effects of underdrainage. The land around Billings is underlaid at a depth of from 6 to 8 feet by a layer of gravel. Within the last few years it has been necessary to construct a ditch around the town of Billings to cut off from the town the seepage waters from the irrigated lands. This ditch is cut to a depth of 6 or 8 feet, so that it is in the gravel through its whole length, and it receives the water from two or three natural draws and all of the seepage water from four or five sections of land. No sewerage is allowed to flow into the ditch from the town.

A number of observations were made upon this ditch during the month of June. It was estimated that the average flow of water during this time was about 40 cubic feet per second. Frequent determinations were also made of the soluble salt content of the water flowing in this drainage ditch.

The following table gives the amount of salt found during the month of June:

Examination of drainage water.

	Salt (per cent).	Tons of salt removed per hour.
June 4	0.302	13.6
June 6	.424	19.1
June 7	.422	19.0
June 11	.449	20.2
June 12	.283	12.7
June 13	.481	21.6
June 16	.227	10.2
Average	.370	16.6

It will be seen that the ditch is doing a great work in removing the salt content from the overirrigated lands around the town. At the rate at which the salt was being removed at the time these observations were made the ditch was removing about 16½ tons per hour. If this rate was continuous it would drain 1 per cent of salt from the upper 5 feet of about 900 acres of land per year. As a matter of fact, while the ditch rarely if ever stops flowing, the flow is not always as great as during the time of this investigation. Still, the figures give some idea of the enormous results which may be accomplished by a judicious system of drainage in the reclamation of these alkali lands and the protection from an undue accumulation of salt and seepage waters.

It may be well to state that the water in the main irrigating canal that is taken out of the Yellowstone River about 40 miles above Billings, although carried for this great distance through the valley, was fresh and free from salts. From all sources, however, where this water was escaping as seepage water it is seen to be loaded with excess of salts, and where free to flow off readily the salts will be carried off instead of accumulating in the alkali flats.

Besides the examination of the drainage ditch around the town of Billings many determinations were made of the salt content of springs and wells. The following table gives the determinations of the salt content from a number of places.

Salt content of springs and wells near Billings.

	Per cent.
Spring on the sandstone bluff	.029
Well on west side of sec. 2, T. 1 S., R. 25 E	.119
Spring on west side of sec. 2, T. 1 S., R. 25 E	.212
Well on north side of sec. 2, T. 1 S., R. 25 E	.309
Spring on north side of sec. 6, T. 1 S., R. 26 E	.433
Spring in center of sec. 5, T. 1 S., R. 26 E	.437
Well on south side of sec. 1, T. 1 S., R. 25 E	.536
Well on north side of sec. 2, T. 1 S., R. 25 E	.538

Well water containing more than one-tenth of 1 per cent is ordinarily considered unfit for domestic use. In most of these wells the water was less than 5 feet below the surface of the ground, and the water tasted strongly saline.

It will be seen, therefore, from all of these sources that the water in the soil is charged with this excess of salt. If there is a ready means provided for it to leave the soil, there will be no excess of soluble salts. It would, of course, be unfortunate to depend upon this to carry off the salts from reckless overirrigation, for in removing these salts much valuable plant food may also be lost and the soil in a measure impoverished. It is necessary, therefore, even with a system of efficient underdrainage, to use great care, so that there shall not be more loss through underdrainage than is necessary. It is perfectly evident, however, on the other hand, that if these conditions continue and the water rises closer to the surface than it is at present, that the seepage waters and the accumulation of salts together are likely to prove very disastrous over larger areas.

Many theories have been advanced by the land owners around Billings, and in these other localities also, as to the source of the alkali and as to the conditions under the surface. The belief is widespread that the alkali flats can probably be reclaimed by flooding the surface during a dry season and washing off the crust. Investigations, however, have shown very conclusively that the crust contains only a very small proportion of the alkali, and that this method alone will not be sufficient to remove the trouble. Many of the planters are beginning to see that the rise of alkali is coincident with the accumulation of seepage waters, and to realize that the trouble is probably due to a too lavish use of water in irrigation.

Hilgard has pointed out for years that the only safe practice in bringing a new area under the ditch, in a soil that is at all likely to have alkali, is to use water very sparingly and keep the land under thorough cultivation, so that a minimum amount of water shall evaporate from the surface of the ground to deposit the salts, and so that there shall be no accumulation of seepage waters in the subsoil.

Hilgard has repeatedly called attention to the reactions between lime salts and the salts of the alkalies.

Where sodium or potassium carbonates or chlorides are associated with calcium sulphate in a well-aerated soil, a reaction takes place in which sodium or potassium sulphate and calcium chloride or carbonate are formed. The calcium chloride is extremely soluble and easily leached from the soil if there is any chance at all of its being carried off by drainage waters. The calcium carbonate is difficultly soluble and would remain in the soil as limestone. On the other hand, where sodium or potassium sulphate exists in the soil, together with lime carbonate and in the presence of an excess of carbonic acid or in the presence of supercarbonates of the alkalies, the reverse action takes place and carbonate of soda or potash is formed, together with the sulphate of lime.

Hilgard shows this reaction actually taking place in certain conditions of the soil. He points out that the carbonate of soda and sulphate of lime may occur in the bottom of a slight depression where the soil is moist, while the sodium sulphate and calcium carbonate will be found around the edges where the soil is better drained. As a practical application of this knowledge, he urges the use of gypsum or sulphate of lime in the reclaiming of lands containing the black alkali or carbonate of soda, and at the same time points out the necessity of thorough drainage in connection with the application of gypsum; otherwise the application will do no good at all.

These various reactions and properties of the so-called alkali salts indicate the methods for the reclamation of the alkali lands. In the case of the carbonates the course recommended by Hilgard is unquestionably the proper one—to treat the soil with heavy applications of gypsum and insure thorough drainage, so as to have the soil well aerated. In the case of an excess of sodium chloride, which is very soluble and easily leached out of a soil, it is only necessary to flood the soil and remove the excess of salt in this way. It is essential, however, that the soil so treated should have good underdrainage in order that the water applied at the surface may percolate through and actually carry off the excessive amount of the soluble sodium chloride. No application of any kind will be beneficial, as the sodium chloride is as simple a salt as one can have and quite harmless, except when present in extraordinary amounts.

The treatment of soils containing sodium sulphate is more difficult than in the case of the chloride, as the salt is less easily leached from the soil. Here, again, no application, however, can be made, the sulphate, like the chloride, being injurious only when in large excess. It will be shown further on that the surest plan in the cultivation of these alkali soils is to use care in applying the water, so that there shall be no accumulation of the salts at the surface, and, as Hilgard has repeatedly recommended, the cultivation should be very thorough so as to prevent, so far as possible, the evaporation of the water from the surface of the ground. When the salts have once accumulated, however, there is nothing to do but wait for them to gradually leach away through the drainage and seepage waters or to thoroughly underdrain the land with tile drains, and so hasten the reclamation.

SUMMARY OF THE INVESTIGATIONS AND CONCLUSIONS.

The results of these investigations show that there is no sodium carbonate or black alkali in the soil. The source of the alkali is in the sandstone, and particularly in the shale or slate rocks from which the soils have been derived. Before irrigation was introduced the salts were present in the soils in rather large amounts, but well distributed, and not in such large quantities as to be injurious to crops. The injury is due entirely to overirrigation, to the translocation and local accumulation of salts by means of seepage waters, and to the imperfect drainage facilities in the compact gumbo soils and the inability of the excess of salts and of seepage waters to escape. The first trouble appears to be due to the seepage waters. This, of course, need not necessarily be so, but it appears to be the case in this locality. The open, sandy lands, having better underdrainage, are not likely to be injured by a rise of salts except from an excessive application of water or in the low places in the path of the drainage system, especially when these are underlaid, as they are liable to be, by the heavy gumbo subsoils. The gumbo soil requires great care in cultivation, as it is easily ruined by the accumulation of seepage waters and the subsequent accumulation of salts. There are many areas in the valley, of course, which have still a low or moderate salt content which are probably safe for years to come. There are other areas in which the salts are now accumulating to such an extent as to render the future value of the land very uncertain, while there are still other areas which have gone beyond this stage, and what were once fertile tracts have been thrown out as barren flats. The investigations show, further, the very disturbing fact that the injury need not be due to a local application of water, but to the injudicious application of large quantities of it in remote localities and on neighboring farms over which the unfortunate person has no control and for the effects of which he has, at present, no redress.

The investigations point clearly to the natural methods of preventing this injury and of reclaiming the lands when once the injury has occurred. There is no question that the injury is due to the translocation and local accumulation of the salts which were formerly well distributed in the soils of the valley. Alkali has been troublesome here only after eight or ten years of irrigation. The trouble is always preceded by an accumulation of seepage waters, followed in a few years by the alkali incrustations on the surface of the land. This evidently points to the necessity of great care in the application of water in the methods of irrigation. This care must be exercised not only for the land which is being irrigated, but for the adjoining lands on lower levels. While a man can overirrigate a sandy tract with practical impunity to himself, he is likely to swamp his neighbor on a lower level. There are involved property rights, therefore, which will come to be recognized and which will have to be taken into consideration in any intelligent and safe system of irrigation.

Where the damage has been done, or where the conditions are so imminent that ultimate ruin can be foreseen, the logical method of reclamation is in providing adequate systems of drainage to carry off the excess of water and the accumulated salts. This is expensive, but it is the only thing in this case to hasten the slow processes of nature, which are entirely inadequate in the presence of the present methods of irrigation and of culture. Underdrainage is expensive, but it has amply repaid for the investment in other localities where land is worth no more than in the Yellowstone Valley. Any land which is worth $50 per acre could well afford to be taxed for underdrainage if it is necessary, as in many places in the Yellowstone Valley, to save the investment from utter annihilation. It may be too soon yet to urge an extensive system of underdrainage in the valley, but some small systems should certainly be introduced, if necessary by cooperation, for an object lesson when it is considered necessary and timely to protect against trouble or to reclaim lands already abandoned. The owners will then see that it is feasible to protect their lands and to reclaim, through underdrainage, those that are abandoned.

It has been pointed out already that there are some crops which can stand much larger percentages of alkali than others. It is quite possible that other valuable crops can be found or can be bred which will stand large quantities of alkali, but it is unfortunate, indeed, for a locality like the Yellowstone Valley, which was originally free from alkali, to accept such conditions resulting from their injudicious methods of irrigation and try to find crops which will thrive upon lands which have been unnecessarily injured.

It must not be assumed, however, that a thorough system of underdrainage relieves one from exercising care and judgment in applying water to the land. There is less immediate danger of ruining the land, to be sure, but there are two things to be considered, namely, that an excessive use of water means just so much loss to irrigation and so much less land which can be brought under the ditch, and also that in the removal of these salts by the flow of the seepage waters out through the drainage system large quantities of really valuable plant food are likely to be removed from the soil. The very accumulation of these soluble salts is due to the arid conditions of the climate. The great fertility of the soil results from the accumulation of these salts, and if we introduce artificial drainage, which will tax the resources of the soil, we may remove in the course of a generation, or even in less time than this, the accumulated results of the changes of vast geologic ages in the disintegration of rocks. By overirrigation and underdrainage we may remove in a few years the very conditions which contribute to the wealth of the country in the fertility of the soil.

In taking up new land in the Yellowstone Valley the heavy gumbo soils should be underdrained at the time the first irrigation waters are applied to the land. Even if the system of underdrainage is not complete at the start, a sufficient amount of it should be put in to answer the purpose at the beginning, and so arranged that it can be extended and more laterals put in as time goes on and the necessity of it becomes apparent. It is too late to wait until the damage has been done, for the accumulation of salts themselves acts on the heavy gumbo soils and makes them more impervious to water and harder subsequently to drain. Great care must be taken in the application of water. As little as possible should be applied at each time, so that there shall be as little waste as possible to go off as seepage water. The surface then should be thoroughly cultivated, unless otherwise protected from evaporation by alfalfa or other close-growing crops, so as to reduce the loss of water from the surface to a minimum and prevent thereby the accumulation of salts at the surface.

The rise in the level of water in wells must be looked upon with uneasiness and guarded against with great care.

The conditions in the Yellowstone Valley are particularly simple, and the danger from the rise of salts may be easily controlled. These investigations show the cause of the trouble, the actual conditions over a small section of the valley, and point out the logical methods of preventing trouble and of redeeming the land after the trouble has come. The locality is fortunate indeed in having no great excess of alkali in the soils previous to irrigation, as occurs over such large areas in adjoining States. The question involved is a simple problem, well within the contról of the intelligent land owners of the valley.

While the discussion of this important subject in the present publication has been confined to the Yellowstone Valley, it is nevertheless one, as already stated in the introduction, of practical interest all through the States of the far West, and the principles applicable in the case under discussion are in general applicable to alkali lands throughout the country.

FARMERS' BULLETINS.

These bulletins are sent free of charge to any address upon application to the Secretary of Agriculture, Washington, D. C. Only the following are available for distribution:

No. 16. Leguminous Plants for Green Manuring and for Feeding. Pp. 24. No. 19. Important Insecticides: Directions for Their Preparation and Use. Pp. 20. No. 21. Barnyard Manure. Pp. 32, figs. 7. No. 22. The Feeding of Farm Animals. Pp. 32. No. 23. Foods: Nutritive Value and Cost. Pp. 32, charts 2. No. 24. Hog Cholera and Swine Plague. Pp. 16. No. 25. Peanuts: Culture and Uses. Pp. 24, fig. 1. No. 26. Sweet Potatoes: Culture and Uses. Pp. 30, figs. 4. No. 27. Flax for Seed and Fiber. Pp. 16. No. 28. Weeds: and How to Kill Them. Pp. 32, figs. 11. No. 29. Souring of Milk, and Other Changes in Milk Products. Pp. 23. No. 30. Grape Diseases on the Pacific Coast. Pp. 15, figs. 3. No. 31. Alfalfa, or Lucern. Pp. 24, figs. 3. No. 32. Silos and Silage. Pp. 32, figs. 10. No. 33. Peach Growing for Market. Pp. 24, figs. 21. No. 34. Meats: Composition and Cooking. Pp. 29, figs. 4. No. 35. Potato Culture. Pp. 23, figs. 3. No. 36. Cotton Seed and Its Products. Pp. 16. No. 37. Kafir Corn: Characteristics, Culture, and Uses. Pp. 12, fig. 1. No. 38. Spraying for Fruit Diseases. Pp. 12, figs. 6. No. 39. Onion Culture. Pp. 31, figs. 3. No. 40. Farm Drainage. Pp. 24, figs. 6 No. 41. Fowls: Care and Feeding. Pp. 24, figs. 4. No. 42. Facts About Milk. Pp. 29, figs. 8. No. 43. Sewage Disposal on the Farm, and Protection for Drinking Water. Pp. 20, figs. 8. No. 44. Commercial Fertilizers: Composition and Use. Pp. 24. No. 45. Some Insects Injurious to Stored Grain. Pp. 24, figs. 17. No. 46. Irrigation in Humid Climates. Pp. 27, figs. 4. No. 47. Insects Affecting the Cotton Plant. Pp. 32, figs. 18. No. 48. The Manuring of Cotton. Pp. 16. No. 49. Sheep Feeding. Pp. 24. No. 50. Sorghum as a Forage Crop. Pp. 20, fig. 1. No. 51. Standard Varieties of Chickens. Pp. 48, figs. 44. No. 52. The Sugar Beet. Pp. 48, figs. 24. No. 53. How to Grow Mushrooms. Pp. 20, figs. 14. No. 54. Some Common Birds in Their Relation to Agriculture. Pp. 40, figs. 22. No. 55. The Dairy Herd: Its Formation and Management. Pp. 24. No. 56. Experiment Station Work—I. Pp. 31, figs. 10. No. 57. Butter Making on the Farm. Pp. 15. No. 58. The Soy Bean as a Forage Crop. Pp. 24, figs. 5. No. 59. Bee Keeping. Pp. 32, figs. 19. No. 60. Methods of Curing Tobacco. Pp. 16. No. 61. Asparagus Culture. Pp. 40, figs. 17. No. 62. Marketing Farm Produce. Pp. 28, figs. 7. No. 63. Care of Milk on the Farm. Pp. 40, figs. 9. No. 64. Ducks and Geese: Standard Breeds and Management. Pp. 48, figs. 37. No. 65. Experiment Station Work—II. Pp. 32, figs. 7. No. 66. Meadows and Pastures in the Middle Eastern States. Pp. 28, figs. 9. No. 67. Forestry for Farmers. Pp. 48, figs. 15. No. 68. The Black Rot of the Cabbage. Pp. 22, fig. 1. No. 69. Experiment Station Work—III. Pp. 32, figs. 2. No. 70. The Principal Insect Enemies of the Grape. Pp. 24, figs. 12. No. 71. Some Essentials in Beef Production. Pp. 24, figs. 17. No. 72. Cattle Ranges of the Southwest. Pp. 32, figs. 9. No. 73. Experiment Station Work—IV. Pp. 32, figs. 3. No. 74. Milk as Food. Pp. 39, charts 2. No. 75. The Grain Smuts: How They are Caused and How to Prevent Them. Pp. 20, figs. 8. No. 76. Tomato Growing. Pp. 30. No. 77. The Liming of Soils. Pp. 19. No. 78. Experiment Station Work—V. Pp. 32, figs. 2. No. 79. Experiment Station Work—VI. Pp. 28, figs. 2. No. 80. The Peach Twig-borer: An Important Enemy of Stone Fruits. Pp. 16, figs. 5. No. 81. Corn Culture in the South. Pp. 24. No. 82. The Culture of Tobacco. Pp. 24. No. 83. Tobacco Soils. Pp. 23, fig. 1. No. 84. Experiment Station Work—VII. Pp. 32, figs. 8. No. 85. Fish as Food. Pp. 30. No. 86. Thirty Poisonous Plants. Pp. 32, figs. 24. No. 87. Experiment Station Work—VIII. Pp. 32, figs. 6. No. 88. Alkali Lands. Pp. 23, fig. 1. No. 89. Cowpeas. Pp. 16, fig. 1. No. 90. The Manufacture of Sorghum Sirup. Pp. 32, figs. 9. No. 91. Potato Diseases and Their Treatment. Pp. 12, figs. 4. No. 92. Experiment Station Work—IX. Pp. 30. No. 93. Sugar as Food. Pp. 27. No. 94. The Vegetable Garden. Pp. 24, figs. 8. No. 95. Good Roads for Farmers. Pp. 47, figs. 49. No. 96. Raising Sheep for Mutton. Pp. 48, figs. 18. No. 97. Experiment Station Work—X. Pp. 32, figs. 5. No. 98. Suggestions to Southern Farmers. Pp. 48. No. 99. Three Insect Enemies of Shade Trees. Pp. 30, figs. 11. No. 100. Hog Raising in the South. Pp. 40. No. 101. Millets. Pp. 28, figs. 6. No. 102. Southern Forage Plants. Pp. 48, figs. 14. No. 103. Experiment Station Work—XI. Pp. 32, figs. 5. No. 104. Notes on Frost. Pp. 24. No. 105. Experiment Station Work—XII. Pp. 32, figs. 4. No. 106. Breeds of Dairy Cattle. Pp. 48, figs. 21. No. 107. Experiment Station Work—XIII. Pp. 32, figs. 3. No 108. Saltbushes. Pp. 20, figs. 9. No. 109. Farmers' Reading Courses. Pp. 20. No. 110. Rice Culture in the United States. (In press.)

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CROPS USED IN THE RECLAMATION OF ALKALI LANDS IN EGYPT.

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CROPS USED IN THE RECLAMATION OF ALKALI LANDS IN EGYPT.[a]

By **Thomas H. Kearney**, *of the Bureau of Plant Industry*, and **Thomas H. Means**, *of the Bureau of Soils.*

INTRODUCTION.

Important projects are now on foot which will lead to a great increase in the area of land under irrigation in the arid part of the United States. But every extension of irrigation is sure to be followed by a "rise of alkali" in the lower levels of the land thus opened to agriculture unless drainage is properly looked after. Hence, the time is opportune for calling attention once more to the "alkali" problem and to ways in which it can be met.

In parts of Egypt, with its hot, arid climate, and its extensive irrigation system, there are great stretches of land that have become too salty to produce crops. There, too, the vexing question of how to deal with alkali[b] calls for an answer. Systematic efforts to wash these lands and restore to them their former fertility are being made on a large scale in Egypt, both by the Government and by private capital. It will be interesting to consider the methods used in this work with a view to applying them as far as possible in the reclamation of alkali lands in the United States. But, as conditions in Egypt are in many respects peculiar, a knowledge must first be had of the climate, soils, and agriculture of that country.

CLIMATE.

The climate of Egypt is arid. Over the greater part of the country there is practically no rainfall, and in no part is there enough to produce crops without irrigation. The temperature is uniformly high. Light frosts occur in the winter, but the growing of citrus fruits is possible throughout the country. That part of the country in the narrow valley south of Cairo has a true desert climate, that is, a very dry atmosphere, with hot days and cloudless skies. Lower Egypt, or the Delta of the Nile, receives the moisture-laden winds from off the Mediterranean, so that the climate differs greatly from that of the desert. At points near the coast the air is moist, while at Cairo, at the apex of the Delta, the influence of the surrounding desert is felt and the air is much drier. In the United States, the region from San Antonio, Tex., to Montgomery, Ala., has a summer climate very similar to that of Lower Egypt. The climate of southern Arizona and southeastern California closely approximates that of Upper Egypt. Both are very dry and hot, but the extremes of cold are greater in our American deserts.

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[a] The observations upon which this paper is based were made in the course of a visit to northern Africa under the auspices of the Office of Seed and Plant Introduction and Distribution, Bureau of Plant Industry. The primary object of this expedition by Messrs. Kearney and Means was to secure seeds of plants suitable for introduction into the arid parts of the United States.

[b] The word "alkali" is used in this paper in its popular sense, as applying to excessive accumulations in the soil of soluble salts of any kind, and not in its strict chemical meaning.

IRRIGATION.

The agricultural lands of Egypt lie entirely within the narrow Valley of the Nile, extending from the first cataract to the Mediterranean, a distance of 700 miles. At Cairo the valley widens into a broad, fan-shaped delta with a level surface, sloping gently toward the sea. On the west side of the Nile Valley, 60 miles south of Cairo, there is a break in the desert hills, and through this depression the Nile water is carried into a valley which forms the province of Fayum.

All of the soils of Egypt are alluvial in origin and have been derived directly from the deposition of mud by the Nile. The Nile rises in Central Africa, in a region of great rainfall, and flows northward across the Sahara Desert. The level of the water in the river is at its lowest stage during May and the early part of June. About the middle of June the annual rise commences and continues until the middle of September. This rise amounts to about 35 feet on the average, and the maximum height is maintained for from four to six weeks, when the water commences to fall, reaching its minimum again in May.

Under the ancient system of irrigation, which has been practiced in Egypt for thousands of years, water from the river at the season of flood is turned into basins (Pl. LXXVIII, fig. 1) which vary in area from 500 to 50,000 acres. Each of these basins is filled with water to a depth of from 3 to 5 feet, and at the end of six weeks the excess water is drained back into the Nile. Crops are then sown upon the mud without previous cultivation. Under this system of irrigation generally but one crop a year is possible.

During the early part of the last century a movement was started which has revolutionized irrigation methods in Egypt. Deep canals were dug so that water could be taken from the Nile at the season of low water, thus permitting irrigation throughout the year. This system of irrigation, which is the one in common use in the western portion of the United States, is known in Egypt as perennial irrigation, and by its use two and sometimes three crops can be grown in a a year. The lands lying immediately along the banks of the Nile are higher than the lands farther away from the stream, so that it is frequently necessary to lift the water up to them by artificial means. To accomplish this there are in use a number of simple water-lifting machines, worked by hand or by animal power. The simplest of

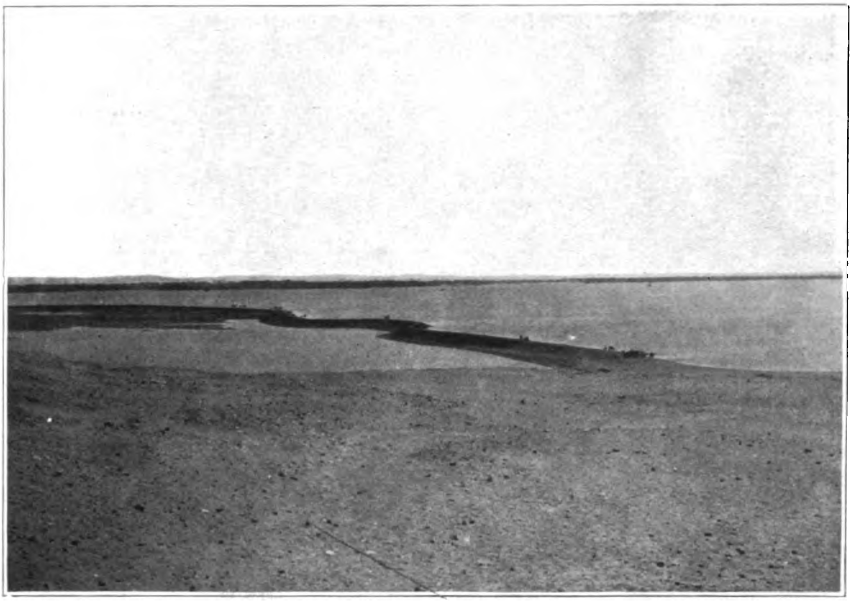

FIG. 1.—BASIN IRRIGATION IN EGYPT.

[The bank between the two basins is used as a road.]

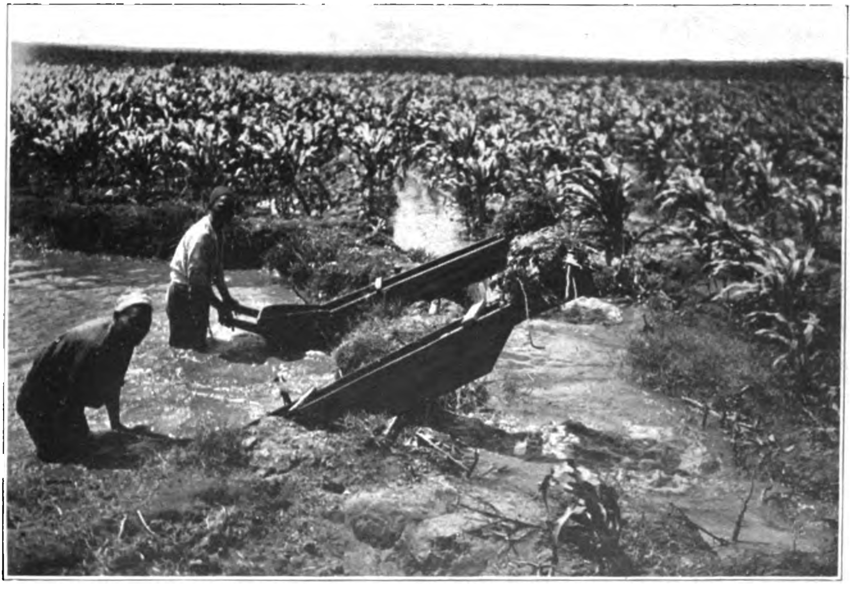

FIG. 2.—ROCKER FOR LIFTING WATER SHORT DISTANCES.

[One of the many simple devices for irrigation in use in Egypt.]

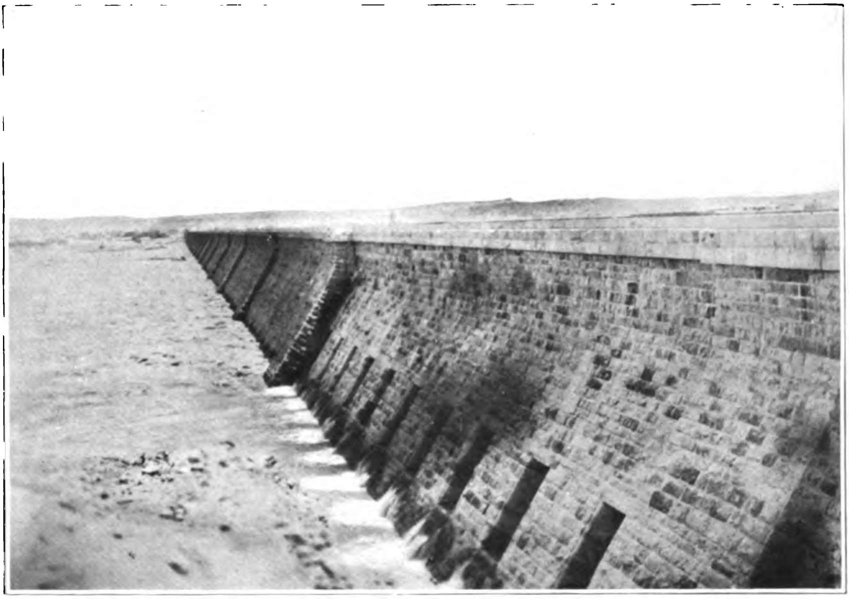

FIG. 1.—THE NILE RESERVOIR DAM AT ASSUAN.

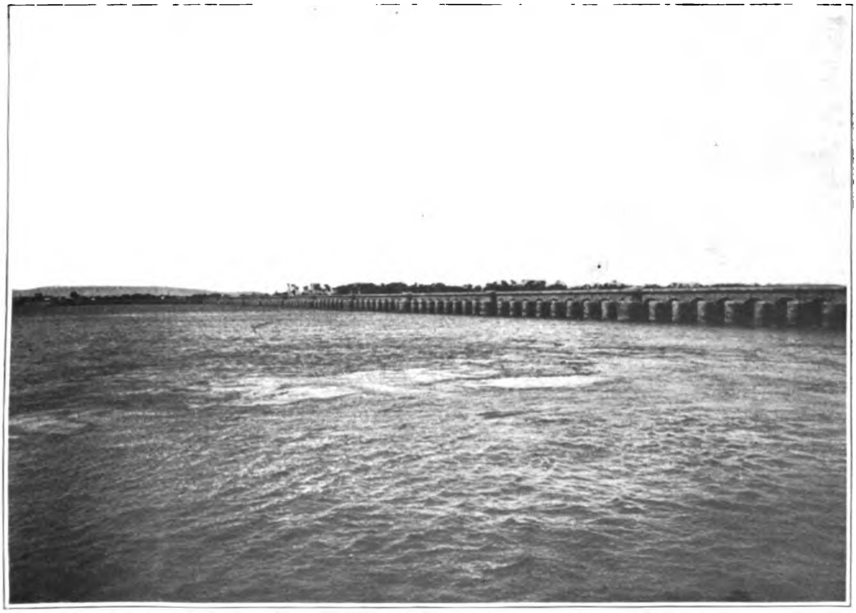

FIG. 2.—THE ASSIUT BARRAGE ACROSS THE NILE.

[The increase in crop values from the use of this barrage the first year exceeded its cost—$1,250,000.]

these is the "shaduf," which consists of a goatskin bucket on the end of a sweep, the other end of which is weighted with a ball of dried mud. Fig. 47 shows the construction and method of operating one of these shadufs. Another method of lifting water in common use is the "sakkia," which consists of buckets on a rope or chain, lifted by animal power. A number of other simple instruments are in use (Pl. LXXVIII, fig. 2). Among these might be mentioned the Archimedes screw, used for short lifts, and in some cases even a basket, suspended by four ropes and swung by two men, is used for lifting water out of a ditch onto the land immediately adjoining.

In striking contrast with these simple and crude methods of irrigation are the massive engineering works recently constructed, or now under construction, by the Government. In the conversion of lands from basin to perennial irrigation it has been necessary to maintain a more uniform supply of water than is ordinarily given by the Nile. The minimum flow of the river is estimated at 8,000 cubic feet per second, while for all the land now under perennial irrigation 20,000 cubic feet per second should be supplied. In order to insure this 20,000 cubic feet per second throughout the season of low water, it has been necessary to conserve a portion of the flood water by the construction of a large dam near Assuan, at the first cataract. This dam is shown in Pl. LXXIX, fig. 1. The dam is 1¼ miles long, and has a height above the gate sills of 70 feet. The reservoir created by this dam stores about 800,000 acre-feet of water, or sufficient to permit of the conversion of about 600,000 acres of land from basin to perennial irrigation. Supplementary to this dam there have been planned a

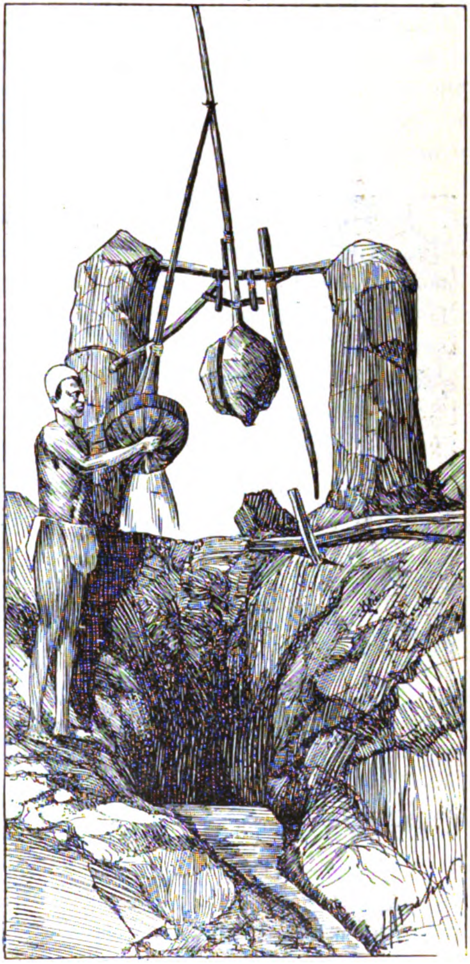

FIG. 47.—Shaduf, used in lifting water along the Nile and large irrigating canals in Egypt, with which water can be lifted 6 or 8 feet.

number of barrages, or diversion dams, at points along the Nile at the heads of the main canals. Of these diversion dams, two have now been constructed, one at Assiut (Pl. LXXIX, fig. 2), which raises the level of water in the river sufficiently to permit of water being taken out during the low season and which feeds the important canals of Upper Egypt, and one at the point where the Nile divides, at the head of the Delta, about 12 miles from Cairo. This barrage consists of two dams thrown across the two arms of the Nile, and raises the level of the water to such a height that the canals which supply Lower Egypt, or the Delta of the Nile, can be kept full of water throughout the season.

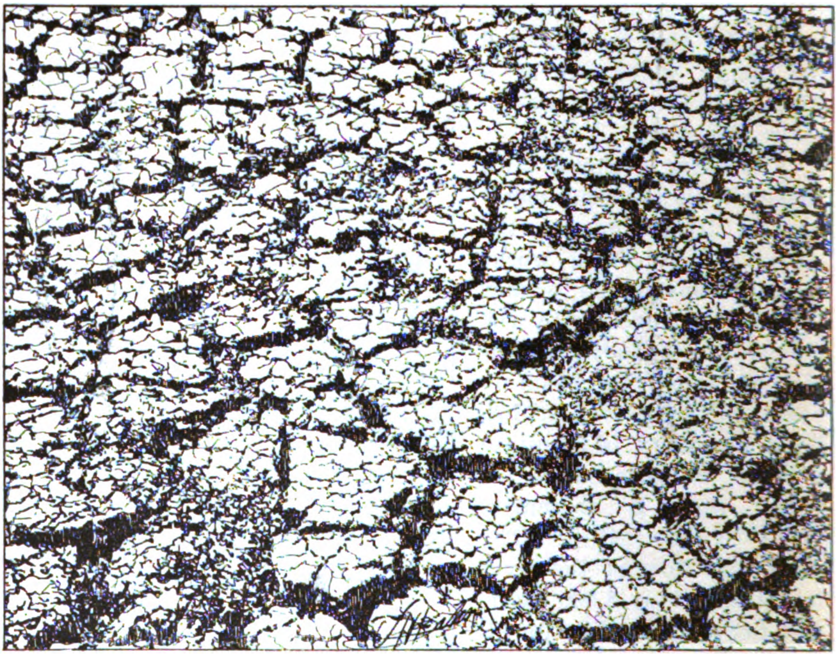

FIG. 48.—Surface of black-clay soil deposited by the Nile, Egypt. Soil cracked like sample shown is considered free from a harmful quantity of alkali.

By these irrigation works, which have been constructed on the most approved plans and at great expense, all of the land of Lower Egypt is now farmed under perennial irrigation, and a considerable percentage of the land of Upper Egypt receives water throughout the year. By these systems the crop-producing capacity of the country has been more than doubled.

SOILS.

The soils of Egypt are alluvial in origin. The typical soil is a heavy, black, sticky clay, which bakes and cracks (fig. 48) as does the bottom of a mill pond when exposed. This soil is difficult to work, but is exceedingly fertile, and its fertility is maintained by the mud deposited by the irrigation waters. The practice of applying commercial fertilizers is gradually becoming general, as it is found that the increase in crop produced by the application of manure more than pays for the cost of manuring.

CROPS GROWN.

Egypt is peculiar among the countries of the world in its agriculture as in other things. It is a one-river country; from the standpoint of agriculture the narrow Valley and the broad Delta of the Nile are almost the whole of Egypt. Agriculture is the life of the country; more so, perhaps, than anywhere else in the world. Agriculture is highly developed, and intensive methods are used in cultivating several of the most important crops. This is rendered possible by the abundance of cheap farm labor. In 1898 it was estimated that there were in Egypt 5,750,000 acres of land either in actual cultivation or in process of reclamation by washing and drainage. Of this, 2,320,000 acres is in Upper Egypt and 3,430,000 in Lower Egypt. The renting value of land in all Egypt was estimated at $106,700,000, representing 57 per cent of the gross yield of the land.

The Egyptian agricultural year is divided into three seasons, that is, the summer, from April 1 to August 1; the flood, from August 1 to December 1; and the winter, from December 1 to April 1. These seasons, of course, overlap to some extent, the summer crops being still in the land when the flood crops are sown. Cotton, sugar cane, maize, sorghum, and rice are among the principal summer crops; sorghum, maize, and rice are also grown as flood crops; clover, wheat, barley, and beans are winter crops.

Upper Egypt differs from the country north of Cairo in the fact that the "basin system" of irrigation (Pl. LXXVIII, fig. 1) is still widely practiced. Of the 2,300,000 acres of irrigated land in Upper Egypt, 1,435,000 is still basin land, and is farmed by methods that have come down with practically no change from the time of the Pharaohs. Of the remainder, two-thirds is subject to perennial irrigation and one-third to irrigation in flood time only. About 2,120,000 acres in Upper Egypt produce winter crops, 370,000 acres summer crops, and 530,000 acres flood crops. The average value per acre of the year's crops in Upper Egypt is estimated by Mr. Willcocks at about $33.50.

The principal winter crops are wheat, beans, clover, barley, and lentils, in large part sown on the basin lands after the flood water has been drawn off, but also extensively grown on the perennially irrigated land. Of summer crops, the most important are cotton, sugar cane, sorghum, garden vegetables, and melons. Of these, sugar cane and cotton are limited to the perennially irrigated lands, while the chief summer crops of the basins are sorghum, millet, and cucumbers. These summer crops are grown only in the lowest part of the basins, where enough soil moisture remains from the preceding flood to produce a crop without irrigation or rainfall. Indian corn, sorghum, and millet are the main flood crops of Upper Egypt, but are, of course, not grown in the basins, which are full of water during high Nile.

Conditions somewhat different from those of the Nile Valley proper are presented by the oasis province of Fayum, where all the cultivated land receives a perennial supply of water from the Bahr Yusuf Canal. Here all of the principal crops of Upper Egypt except sugar cane are extensively grown on the well-drained lands, while rice and "samar" are grown in some quantity in low lands. In addition, olives, figs, grapes, and other fruits are produced, and there are great numbers of date palms, often of excellent varieties. The Fayum, together with the part of the Nile Valley that lies between Cairo and Beni Suef, produces the great bulk of the date crop of Egypt.

From Lower Egypt the basin system has practically disappeared, and all land of any considerable value is irrigated by the perennial method. About 2,140,000 acres in this part of the country is planted to winter crops, 1,670,000 to summer crops, and 980,000 to flood crops, the same land in many cases producing a winter crop and a summer or a flood crop in the same year; hence winter crops cover 60 per cent, summer crops 50 per cent, and flood crops 30 per cent of the total cultivated area. Mr. Willcocks computes the average total value of the year's crops from an acre of land in Lower Egypt to be about $34.50 and the net mean profit at $20 to $22.50.

The more important winter crops are the same as in Upper Egypt, while in addition the growing of early garden vegetables—onions, potatoes, tomatoes, etc.—for the European markets is becoming an important industry, particularly near the coast. Bananas, oranges, and other tropical or subtropical fruits are also produced. The chief summer crops are cotton, maize, sorghum, Sultani rice, various garden vegetables, and a limited amount of sugar cane. Of flood crops, maize and Sabeini rice occupy the largest area and furnish a large part of the food of the agricultural classes.

The great staple of Egypt to-day is cotton, although hardly eighty years have passed since its cultivation was first introduced. So remunerative is this crop that almost the whole agriculture of Egypt is subordinated to it, and is necessarily one-sided. Land that will bring a good crop of good cotton can rarely be used to better advantage in other ways. The estimated area in cotton in 1897 was 1,200,000 acres, the annual production aggregating 550 million pounds. The average yield of fiber per acre for the whole country is computed to reach the remarkably high figure of 460 pounds; while on an acre of average good land 500 to 600 pounds of fiber are obtained, and from very good lands in one or two provinces 700 to 800 pounds can be expected.

Maize and sorghum are leading crops in all parts of Egypt, affording a large part of the food of the "fellaheen," or peasantry. Rice, extensively grown in the low lands of the Delta, is likewise a very important article of diet in Egypt. Sugar cane is the chief staple in much of Upper Egypt.

Of winter crops, berseem, or Egyptian clover, in rotation with cotton and other crops, is of immense value as a restorer of nitrogen to the soil and as a forage plant. It is vastly more important than alfalfa in Egypt. Hard wheats, barley, and broad beans are also extensively grown in all parts of Egypt.

ALKALI.

More than a thousand years ago, at the time of the Arabian conquest of Egypt, large areas of land lying close to the Mediterranean and only a few feet above sea level were devastated and allowed to lie idle. Portions of this land are to-day covered with sea water at high tide, and other portions have been subject to evaporation for long periods of time. The result has been that there are now large areas containing an excess of salt and alkali which at the present time are out of cultivation. In Upper Egypt other areas have been allowed to lie idle for shorter periods—forty or fifty years—and the result there has been that alkali has risen to the surface. The change in the method of irrigation has had something to do with this, for where land is flooded for only six weeks, as was formerly the practice throughout the country, the water removes most of the salt, or else washes it down so deep that it can not readily return to the surface.

RECLAMATION OF ALKALI LANDS.

There has probably been more work done in the reclamation of alkali and salt lands in Egypt than in any other country. It is estimated that fully half a million acres of land more or less charged with alkali salts have been brought back into cultivation, and that there are still over a million acres unreclaimed. Extensive operations are now being carried on for the reclamation of this land. As the subject is becoming one of great importance in the United States, a description of the methods in use in Egypt should be valuable to the farmers of arid America.

The methods in actual use are varied to suit the local conditions, but in general it can be said that the method consists of dividing the land into small tracts of about 3 acres by drainage ditches, dug to a depth of 2½ or 3 feet, and flooding each of these tracts until the salt is removed through the drains. The drains are usually 150 feet apart, though in the lighter soils and those containing a small percentage of salt the distance is increased to 300 feet.

The cost of reclamation is variously estimated at from $15 to $30 per acre, and it is thought that the average is not far from $20. To thoroughly reclaim the land, washing is carried on for from one to four years, depending upon the nature of the soil and the ease with which the salt is washed away. In many places, however, this time is not lost, but crops of value are grown while the washing is going on. As during much of this time the land is flooded to a depth of at least 4 inches, it is necessary to grow such crops as will live with their roots in standing water. The most important crops at present in use in Egypt are rice (Pl. LXXX, fig. 1), barnyard grass (Pl. LXXXI, fig. 2), and a reed called "samar" (Pl. LXXXI, fig. 1).

At the end of the period of preliminary washing, during which these crops are grown, Egyptian clover and cotton are planted. In rotation with these crops occur further periods of washing, either without crops or with rice, barnyard grass, or samar. By this method of flooding and washing in alternation with ordinary cultivation, the alkali salts which rise during the season when flooding is intermitted are washed out into the drains and entirely removed. As soon as the salt has been washed down to the level of the bottom of the drains it is no longer necessary to flood the land during part of the year, but ordinary crops, varied according to the judgment of the individual farmer, are grown.

CROPS USED IN THE PROCESS OF RECLAMATION.

Three plants are especially popular in Egypt for this purpose—barnyard grass, rice, and samar. All of these have one useful quality in common: They will thrive in the presence of great quantities of water; consequently the work of washing the land can go on unhindered while the crop is standing. There is considerable difference of opinion in Egypt as to which of these plants is most resistant to alkali, but other conditions generally determine which shall be used in a given area.

BARNYARD GRASS, OR DINEBA.

Barnyard grass (*Panicum crus galli*), generally known in Egypt as "dineba," is the crop most extensively used, and is probably the most generally useful. (Pl. LXXXI, fig. 2.) Its use is widespread in the northern part of the Delta, near the Mediterranean coast. In order to give some idea of the part played by this plant in reclaiming salt lands, its use by the Abukir Land Company, near Alexandria, will be described.

This land, in its unreclaimed state, presents an almost perfectly level expanse (the bed of the ancient Lake Abukir), with a rather sandy soil, containing sometimes as high as 10 per cent of common salt, strewn with sea shells, and entirely devoid of vegetation. The drainage ditches and subsidiary irrigation canals having been constructed, the land is flooded to a depth of 4 inches, and is kept flooded for six months, if possible, commencing in autumn. Almost immediately after the digging of drainage ditches the accomplishment of the first stage in the "sweetening" of the soil is betrayed by the

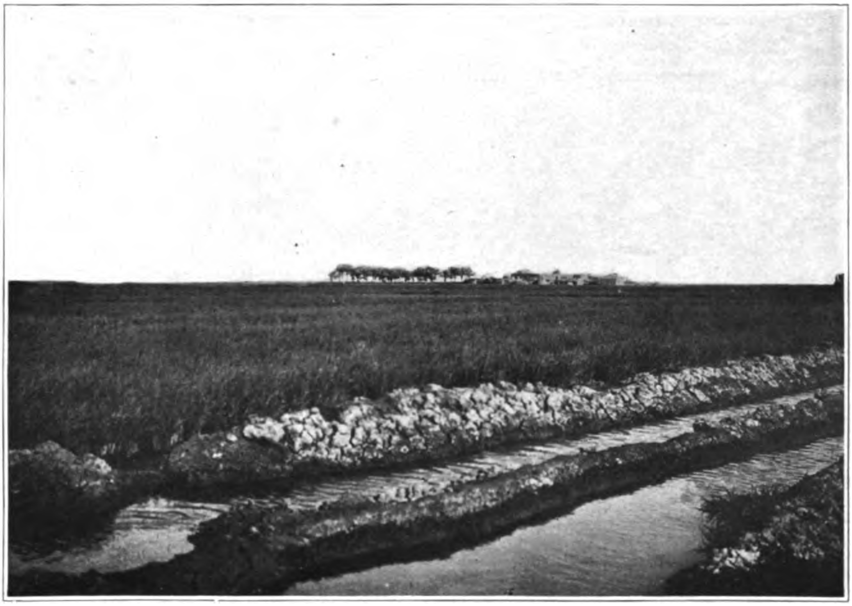

FIG. 1.—RICE GROWN DURING RECLAMATION OF ALKALI SOIL NEAR BUSILI EGYPT.

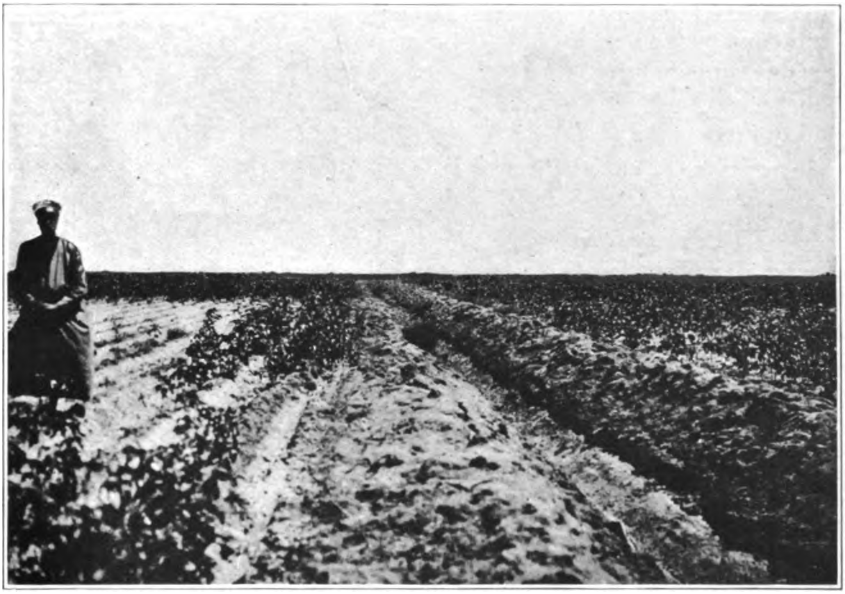

FIG. 2.—RECLAMATION OF ALKALI LAND AT ABUKIR, EGYPT.

[To right of drainage ditch land is reclaimed and cotton is growing; to left of ditch is an alkali spot requiring further washing.]

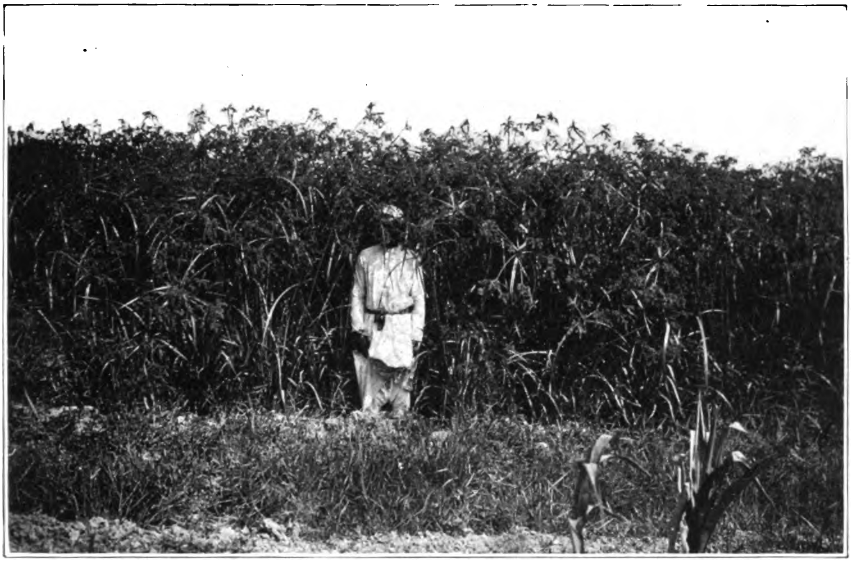

FIG. 1.—SAMAR, USED FOR MAKING MATS, GROWN ON ALKALI LAND DURING THE PERIOD OF RECLAMATION.

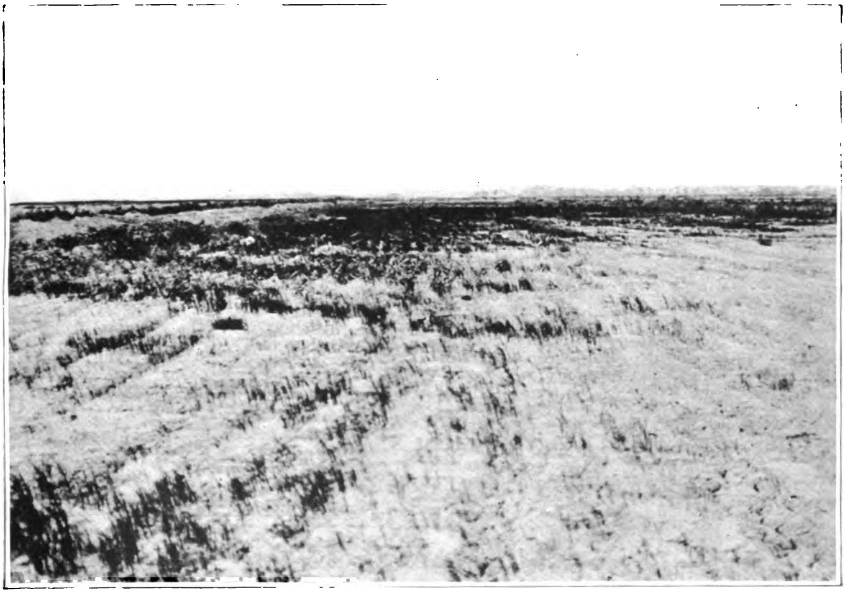

FIG. 2.—PARTIALLY RECLAIMED ALKALI LAND AT ABUKIR, EGYPT, WASHED TWO YEARS AND SOWN WITH "DINEBA," OR BARNYARD GRASS.

appearance of a sort of pickle weed, and later of tamarisk, on the hitherto bare land.

If its condition after this first flooding appears to warrant the step, the land is plowed and a test crop of "dineba" is sown broadcast, generally about July 1. In case a stand of dineba, even though a poor one, is secured, the land is considered fit for berseem, which is sown at the beginning of autumn, immediately after the harrowing and second flooding, which follow the removal of the dineba. The seed is sown broadcast on the still wet soil. If, however, dineba has not given a fair stand, the land is kept flooded during the second winter, and a second test crop of dineba is sown the following summer. On the other hand, the success of the winter crop of berseem is considered sufficient evidence that the land is ready for cotton, which is put in the following spring.

The transition from bare, salty lake bed to productive cotton fields generally requires about three years under this method of treatment. Particular care is taken during this period not to plow to a greater depth than 6 or 8 inches, in order to avoid mixing the subsoil (which at a depth of 2 feet, or sometimes less, remains quite salty) with the washed surface soil. For this reason only the shallow native plow is used. Nor can cultivation be relaxed, even for only a few months, after reclamation has once begun. The salts in the lower levels of the soil soon reach the top again if the land is left fallow, in which case the entire process must be repeated. Eternal vigilance is assuredly the price of safety in reclamation work of this sort.

Dineba probably owes a large part of its usefulness in this regard to other things than an essential hardiness in the presence of salt. Being a shallow rooting plant, and being grown under these reclamation conditions with frequent and abundant floodings, it is probable that the roots go no farther into the soil than the depth which is kept thoroughly washed during the entire life of the plant. As a matter of fact, determinations of salt content of the soil in dineba fields near Alexandria showed the plants to be entirely killed off or prevented from growing at all by a comparatively small amount (0.7 to 1.4 per cent) of salt in the surface foot of the soil, while healthy plants were not found in the presence of more than 0.6 per cent soluble salts in the surface foot.[a] These facts would indicate that this grass is actually less resistant than such deeper rooting plants as alfalfa and cotton; but, as the culture of the latter crops does not permit incessant flooding of the land, they are not adapted to use in the first stages of reclamation. Some authorities in Egypt regard dineba as more resistant than rice, but a few observations made by the writers point to the opposite conclusion. Sorghum, which under American conditions will probably be found a more useful reclamation crop than dineba, is essentially a much more resistant plant.

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[a] Mr. Anderson, manager of the Abukir company's lands, states that dineba can endure the presence of 2 per cent of salts, and will attain its full growth in 1 per cent. His results are probably based upon soil samples taken to a greater depth than the surface foot or two, the subsoil on much of the Abukir land being decidedly saltier. But it is not likely that dineba roots go deeper than 1 foot into the soil.

The cheapness of the seed is another important factor in the choice of dineba as a reclamation crop. Being an abundant weed in rice fields, its seeds form a large part of the screenings, and can be bought at Rosetta for less than $1 per bushel.

Dineba is either pastured off standing or is cut and fed green. A good crop can sometimes be cut or grazed off twice during the six or eight weeks it is in the land. This grass is particularly relished by the water buffalo, which is so important a farm animal in Egypt. In favorable locations good pieces of standing dineba were sold off the land, for cattle feeding, at the rate of $7.50 per acre, in 1900.

SORGHUM.

Sorghum, a small, loose-headed variety of *Sorghum saccharatum*, locally know as "negro," is sometimes planted instead of dineba as a first crop on salt lands in process of reclamation; but its importance in this regard is overshadowed in Egypt by that of other crops. Sorghum grown on such land is generally fed to stock, although the grain grown on other soils is an important article of food with the "fellaheen" or agricultural laboring class.

RICE.

Rice is the second great reclamation crop of the country. (Pl. LXXX, fig. 1.) The rapidly growing, although otherwise inferior, "Sabeini" variety is preferred for this purpose, although not because it appears to be a more alkali-resistant kind. It is not sown before the beginning of August, when the Nile flood is almost at its height and water is abundant. On the other hand, "Sultani" rice, although a more valuable grain, must be sown in May in order to ripen its seeds by October, and this requires much water in the early part of the summer before the flood has begun. In seasons of exceptionally low Nile, such as have recently occurred for several successive years, Sultani rice must suffer in some localities in order that the more important cotton crop receive plenty of water during the early part of the summer, so that this variety is not generally adapted to use as a reclamation crop. The Sabeini variety occupies the land only about seventy days, ripening at about the same time as Sultani. The introduction into Egypt of a variety of rice that will grow as rapidly as Sabeini, but yielding a more valuable grain, would be a great boon to owners of salty land in the northern part of the Delta.

As in the case of dineba, the use of rice as a reclamation crop probably depends largely upon its power to withstand the abundant water with which the land is flooded and washed while the crop is growing. Its roots are very shallow, and probably do not penetrate deeper into the soil than the limit reached by the water with which it needs to be frequently and abundantly flooded to secure a good crop; it is given about as much water as the drainage ditches can take care of. The subsoil, where salts are accumulated in greater quantity, is probably out of reach of the roots, yet on the whole rice appears to be more resistant than dineba to an excess of salts. An examination was made of the water standing on a field planted to rice and in process of reclamation near Alexandria, and the water was found to contain 150 parts per 100,000 of soluble salts, while the first foot of soil under the water contained 0.8 per cent of soluble salts. A good stand of rice was secured here. In a field in the same neighborhood rice was just growing in a soil containing as high as 1.8 per cent of salt in the surface foot. The general opinion appears to favor the view that it is a distinctly alkali-resistant plant. The limit of endurance for Sabeini rice, as determined by Mr. Lang Anderson, of the Abukir company, is about 0.5 per cent soluble salts in the soil. To what depth is not stated.

The seed of Sabeini rice costs two and one-half times as much as that of dineba, and the labor involved in producing a crop is much greater, but, on the other hand, the crop is more valuable. Yet, unless the yield is good, this kind of rice is not considered a paying crop. It requires much more water than dineba, but as it is a "Nili" or flood crop this is not a serious objection. In fields that are not to be permanently devoted to rice cultivation the series of crops on the gradually improving land is practically the same as in the case of dineba, berseem following rice as a winter crop, and being succeeded in its turn by cotton, the goal of most reclaimers of alkali land in Egypt.

Rice is frequently used by the fellaheen in their attemps to reclaim small fields by surface flooding (colmatage) without underdrainage. In such cases the crop is often a failure the first year, but generally succeeds the second season. But when another crop, cotton, for example, is tried in land thus treated, it is quickly seen that permanent reclamation can rarely be accomplished in this way. The salts soon rise once more to the surface.

SAMAR.

Samar (*Cyperus laevigatus*) is grown as a reclamation crop, chiefly in the Wadi Tumilat region, in the eastern part of the Delta. (Pl. LXXXI, fig. 1.) It is a reed, closely related to the papyrus plant, which furnished the ancient Egyptians with writing paper. Like rice and dineba, it is essentially a marsh plant and can endure for a long period the presence of large quantities of standing water, the crop being kept flooded as much as the water available will permit. This, with its shallow habit of rooting and its rapid growth, renders it peculiarly useful as a reclamation crop.

That samar is essentially alkali-resistant is very doubtful. It is more likely that its value as a reclamation crop depends chiefly upon the fact that the roots do not penetrate below the stratum of soil that is kept thoroughly washed by flooding. Those who have watched the behavior of both crops upon salt land are of opinion, however, that samar will resist larger amounts of salt than will rice. Mr. Langley, inspector of the First Irrigation Circle in Egypt, who has given considerable attention to this crop as an aid in reclaiming alkali land, states that "the success of samar is assured where rice can not grow the first year." He maintains that although some land is too salty even for samar without a preliminary year of washing, it can safely be put in upon land too salty to produce a crop of rice, and that it is further preferable to rice in being able to go without watering from ten to twenty days without serious injury. This recommends its use in parts of the Delta where the amount of water available in summer is insufficient to insure a constant supply for rice. Mr. Langley also believes that samar "absorbs salt from the soil more rapidly than any other crop, and that it ameliorates the land more successfully than rice culture, especially in the first year." If this is really the case, the nature of the crop being such that the great bulk of it is entirely removed from the land, samar should prove a very effective agent in reclaiming salty soils.

The production of a good crop of samar is regarded by Mr. Langley as a sufficient indication that the land is ready for rice or for berseem, to be followed in the succeeding summer by cotton.

The three-year rotations chiefly practiced in reclaiming salt lands of the Wadi Tumilat region are as follows:

(1) LAND VERY SALTY.—Washing, samar, cotton. If the cotton succeeds, the reclamation is considered complete. Otherwise recourse is had to samar for another year, and the land is thus rewashed.

(2) LAND MODERATELY SALTY.—Samar, rice, cotton; or rice, samar, cotton; or samar, samar, cotton.

(3) LAND SLIGHTLY SALTY.—Samar, cotton, maize,[a] the last being recognized as a less resistant crop than cotton. In newly reclaimed land the advantage is recognized of returning every three or four years to rice or samar, with the accompanying thorough washing, even though crops of cotton or of maize have been produced in the

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[a] Sometimes the land is merely washed in summer, sown to berseem the same fall, and to cotton the following spring. In other cases a winter crop of barley, succeeded by a summer crop of maize, follows the first summer's washing. Generally, however, samar is the first crop.

meantime, as a means of preventing the return of salts to the surface of the soil, particularly in the neighborhood of drains.

The following will give some idea of the efficacy of samar as a reclamation crop: Mit Afifi cotton in the Wadi Tumilat region yielded 200 to 300 pounds of fiber on newly reclaimed land which had borne a crop of rice the year preceding and of samar the year before that. Twelve cents a pound was obtained for such cotton in 1901 and 17¼ cents in 1900. A crop of equally good appearance was produced on land that had borne samar the previous year and had received its first washing the year before that. Land which had been in rice the year before, preceded by a year of samar, brought about 20 bushels of shelled maize to the acre. Another field, which had been washed only the preceding summer and sown to barley during the intervening winter, brought 35 to 40 bushels when planted with seed of an American variety of maize ("Durra Amerikani"). An examination of the soil in this field showed that very little salt—less than 0.3 per cent—remained in the surface foot.

Samar is sown between the 1st of April and the end of July, while the crop is removed from the land from July 1 to November 30, according to the date of sowing. Instead of seed, pieces of the rootstock, set out at intervals of 18 inches, are planted. The plants grow rankly to a height of 6 or 8 feet. An objection to the use of this plant in rotation is that its roots and rootstocks form a strong mesh in the soil. Much labor is needed to remove this tangle of underground parts before other crops can be put into the land.

Apart from its value as a "reclamation crop," samar furnishes material for making basket-ware and mats of excellent quality. These mats have long enjoyed a reputation in the local market, and are becoming known elsewhere. They are woven from strips made by splitting the previously dried triangular stems. Attractive patterns in various colors are produced. The net value of the crop from an acre of good samar is said to be about $35, while an acre of rice is worth in the same region about $25, after deducting the expense of growing it. Samar mats sell in the local market at about 30 cents a square yard.

BERSEEM.

Berseem, or Egyptian clover, being capable of growing in flooded soils, finds an important place in reclamation work. It is a winter crop, and almost invariably follows the summer crop of dineba, rice, or samar, where one or the other of these serves as the first test crop in salt land. For Upper Egypt especially, where questions of water supply do not permit the extensive use of the latter crops, Mr. Willcocks has recommended the abundant flooding of the winter crop of clover, in connection with the establishment of proper underdrainage, as an efficient means for washing out the salts as often as they show a tendency to accumulate near the surface.

Berseem has been thought to be somewhat resistant to alkali, but is even less so than dineba, according to results obtained by the writers. Mr. Anderson, of the Abukir Land Company, puts its limit of endurance at 0.5 per cent, hence somewhat lower than that of alfalfa in the United States. It is probable that the shallow rooting habit of the plant and the abundant watering it receives tend to keep the small depth of soil reached by its roots thoroughly washed; and that this largely accounts for the supposed power of resistance, just as in the case of rice, dineba, and samar.

COTTON.

Cotton is much grown in Egypt upon land that is more or less salty, particularly in those areas near the coastal lakes of the Delta, where reclamation has been undertaken upon an extensive scale. Since alkali is more or less abundant in parts of the Southwestern United States, where an effort is being made to introduce the cultivation of Egyptian cotton, the facts as to its degree of resistance are much needed. A good opportunity was offered to study this question at Abukir, near Alexandria, where cotton is generally planted wherever reclamation has been going forward for several years. Occasional fields, where the washing has not yet been thoroughly completed, show spots of salty land among the healthy cotton, with perhaps a few scattered salt weeds or an occasional more resistant cotton plant to accentuate the bareness of the ground. (Pl. LXXX, fig. 2.) In such spots careful borings were made, first amid the good cotton, then at the roots of the scattered more resistant plants, and finally in the bare spots where no cotton grew. The percentage of salt content of the surface 2 feet of soil was ascertained to be in each case, as follows: Healthy stand of cotton, 0.6; occasional resistant plants, 1.8; bare spots, destitute of cotton, 2 and over. These figures indicate an unexpectedly high degree of resistance in the cotton plant, marking it as one of the very foremost in this respect of the world's great crops. That cotton is alkali resistant was already more than suspected, however. Reports received last spring from the Pecos Valley in Texas and New Mexico pointed to this conclusion with respect to ordinary Upland cotton. In Egypt, too, the fact is well known. Mr. Foaden, secretary of the Khedival Agricultural Society, wrote some years ago:[a] "The percentage of sodium chlorid present in the majority of the soils of the cotton-growing district is somewhat high. The average of the analyses already given is 1.5 per cent, and it may certainly be said that in the great majority of soils 1 per cent and over would be found."[b]

Jannovitch cotton, of which seed was imported into the United

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[a] Bulletin No. 42, Office Experiment Stations, U. S. Dept. Agr., p. 11.

[b] This statement is probably based upon analyses of samples taken to a greater depth than 2 feet, as otherwise it almost certainly overstates the case.

States by Mr. Fairchild, of the Department, is reported by him to have grown in soils containing 1 to 1½ per cent of alkali. There was formerly cultivated in Egypt a kind of cotton known as "Gallini," supposedly a derivative of American Sea Island. This variety was reputed to be more resistant to alkali than other types of cotton grown in Egypt, although in most respects it did not answer to Egyptian requirements. The fiber is described by Mr. Foaden as of good quality, although the yield per acre was comparatively small.

The effect of considerable salt in the soil upon the quality of the cotton fiber does not appear to be harmful, provided the amount of salt does not greatly exceed 1 per cent. Indeed, there appears to be a belief, not only among the fellaheen but on the part of well-informed observers, that a positively beneficial effect is exerted, at least by common salt (sodium chlorid). Mr. Bonaparte, of the Khedival Agricultural Society, states that an overproduction of leaf and stalk is avoided, and a tendency to ripen early is developed in cotton grown in salty land. Length, strength, and color of fiber are quite commonly believed to be improved by the presence of a moderate amount of salt in the land or the irrigating water.

Even where a considerable amount of salt is present, as in certain soils around Alexandria, Mr. Foaden found the fiber to be "not so inferior as might be expected." The strength was fairly good, but the fiber was shorter than in less salty land. The tendency to earlier maturity of the crop in "alkali" land is shared by cotton with many other plants. As a similar effect is known to be commonly produced in dry soils and dry weather, we have here further evidence that a salty soil, even though saturated with water, is dry to the plant because of the increased difficulty experienced by its roots in taking up water.

As to the effect upon yield of the presence of an excess of soluble salts in the soil, there is as yet no definite information. It is a question well worth investigating both by direct experiment and by the comparison of returns of yield from salty land with those from land where there is no excess of salts.

CONCLUSION.

Of the crops used for the specific purpose of aiding in reclaiming alkali lands in Egypt, probably only two, sorghum and berseem, will be found practically useful in the United States. In almost every important area known to the writers where the accumulat of "alkali" in the land is a serious problem, the water supply
in summer is too scanty to allow the extensive use of di
samar, even were any of these crops suitable to Americ
to labor, market, and general agricultural method
enjoys a considerable reputation in the So

for use in reclaiming salt land, and its use will probably continue to increase. Barley appears to be on the whole the most useful winter crop for such land. Berseem offers great possibilities in the southern part of the arid region as a forage crop and a soil renovator in rotation with cotton, and as a winter soiling crop in orchards. It may very probably find still another important function, that of an agency in reclamation, wherever the abundance of the water supply in winter will warrant its use. A thorough trial of this clover where salt lands are to be reclaimed is therefore most desirable, particularly in the Southwestern States and Territories.

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